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STUDY AND DEVELOPMENT OF TURBOFAN NACELLE MODIFICATIONS TO MINIMIZE FAN-COMPRESSOR NOISE RADIATION

Volume VII - Subjective Evaluation Tests

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16. Abstract

Judgments of relative annoyance caused by flyover noises from a standard Boeing 707-320B and one with acoustically treated nacelles were made by 180 persons. The primary aim of the experiment was to determine if the noise reductions measured during previous flight tests of the acoustically treated nacelles would be perceived by a sample of persons from the community. This aim was achieved by determining the extent of relationship between the noise ratings of the 180 judges and each of 18 engineering calculation procedures that convert sound pressure spectra into subjective units.

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STUDY AND DEVELOPMENT OF TURBOFAN NACELLE MODIFICATIONS TO MINIMIZE FAN-COMPRESSOR NOISE RADIATION

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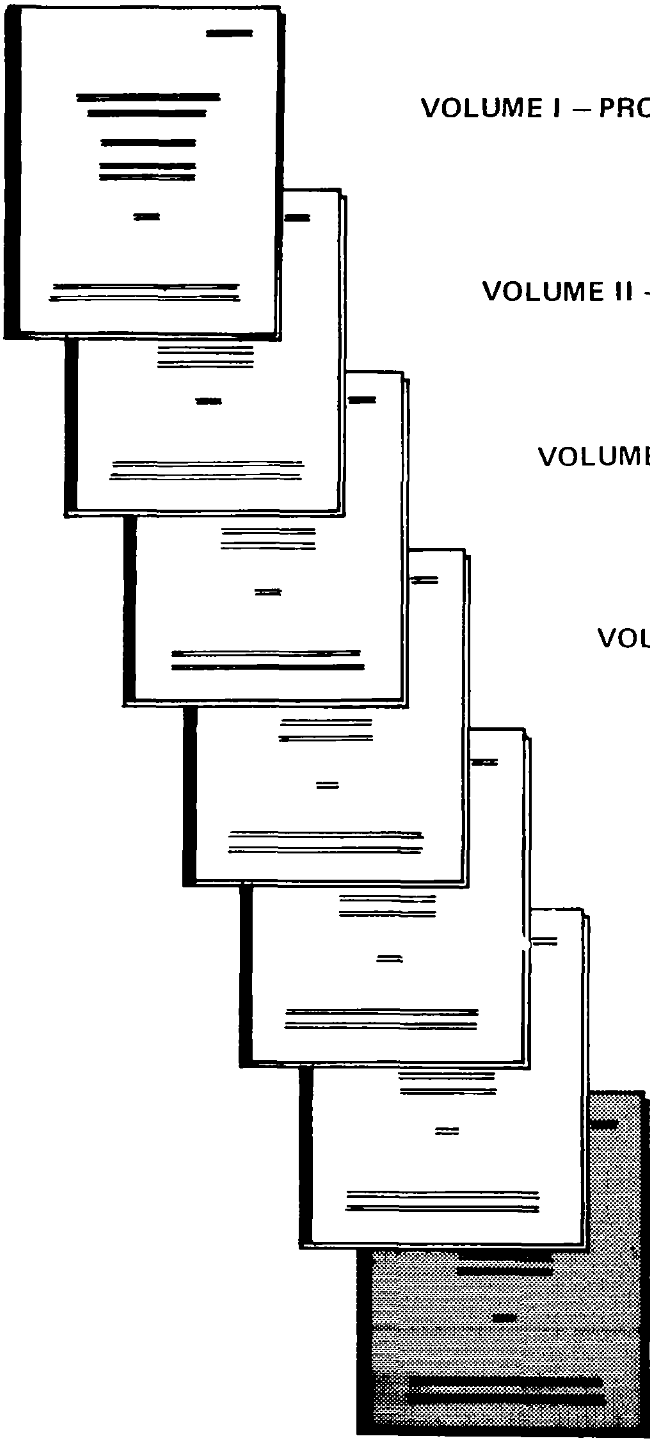

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STUDY AND DEVELOPMENT OF TURBOFAN NACELLE MODIFICATIONS TO MINIMIZE FAN-COMPRESSOR NOISE RADIATION

VOLUME VII

SUBJECTIVE EVALUATION TESTS

The Boeing Company
Seattle, Washington

SUMMARY

Judgments of the relative annoyance caused by the noise of aircraft flyovers and artificial noise were made by 180 persons, equally divided among six listening positions. The judgments were obtained during sessions lasting approximately 2 hr each on two consecutive days. Reactions to flyover noises from a standard Boeing 707-320B and one with the nacelles treated for noise reduction were of primary interest. However, because the study was carried out at an airport, reactions to aircraft routinely using the airport were also obtained.

The primary aim of the experiment was to determine if the noise reductions measured during the flight evaluation of the nacelles, as reported in volume IV, would be perceived by a sample of persons from the community. This aim was achieved by determining the extent of the relationship between the noise ratings of the 180 judges and each of 18 engineering calculation procedures that convert sound pressure spectra into subjective units. Rate of change of annoyance for change of sound level for each calculation procedure was also considered in selecting the procedure that best reflected the judges' ratings. An approach was used that permitted comparisons between previous laboratory experiments and this more realistic field test approach. The general approach was as follows:

- As much as possible, considering weather and operational variables, the judges were exposed to the same range of noise levels and reductions as described in volume IV.

- The judges were tested with "standard" noises from loudspeakers and proved to be performing their task properly as compared to previous experiments under more rigid laboratory conditions.

- The judges' responses to the two airplanes, and the noises of other aircraft using the airport, were correlated with the 18 engineering calculation procedures. Special attention was devoted to perceived noise level (PNL) and effective perceived noise level (EPNL) because these procedures were used to describe nacelle noise reductions in volume IV.

The results lead to the following conclusions:

- Perceived loudness level (PLL) and PNL are equally applicable as evaluation methods for aircraft flyover noise. Correlation coefficients for PNL were 0.94 and 0.91 for the two days; for PLL the values were 0.93 and 0.90.

- Corrections to PLL or PNL for tones (discrete frequencies) or for tones and durations of the flyovers generally lowered the correlation coefficients.

- Since the correlation between the judges' ratings and the PNL calculation procedure was satisfactorily high, it is concluded that the noise reductions described in units of PNdB in table I of volume IV are perceived by persons from the community. For example, people hearing conditions for landing approach, at 6500 pounds of thrust at the 1 nautical mile point, under varied weather conditions would perceive the measured noise level reduction of 14.5 PNdB. Likewise, persons from the community are expected to perceive the noise reductions described in volume IV for the other operating conditions.

INTRODUCTION

In May 1967, The Boeing Company was awarded NASA contract NAS 1-7129, "Study and Development of Turbofan Nacelle Modifications to Minimize Fan-Compressor Noise Radiation." The final phase of the program involved flight tests using a 707-320B/C airplane with acoustically treated nacelles. The effectiveness of the nacelles in reducing measured noise levels at various monitoring stations around an airport was evaluated by flying the untreated airplane for various defined conditions (thrust, altitude, etc.), and then fitting the treated nacelles on the same airplane and repeating the flight conditions. When the effects of atmospheric absorption were removed from the two flight series, the difference between the baseline data and the data for the treated airplane was attributed to the noise reduction achieved by the nacelles. (See vol. IV.)

At the end of this program, the existence of the treated airplane provided a unique opportunity to conduct an experiment directed toward obtaining a sample of community reaction to the noise-reduction efforts. For instance, it was important to know how the community would judge the annoyance change due to the nacelle modifications: Would a measured suppression of 15 dB between the airplanes at approach conditions 1 n. mi. from touchdown be worth 15 dB in the opinion of the exposed population? Also, when the observation point was moved to the sideline, where the atmospheric attenuation reduced the noise differences caused by the nacelles, would this loss in noise reduction be revealed in the observed reaction of a community?

To determine if the measured differences found in the first part of the flight test program were perceived by a sample of persons from the community, the following methods were used:

- The most valid noise-reduction measurement procedure was determined; i.e., one that best agrees with the judges ratings. The bases for this evaluation was the widely used noise rating approaches, perceived loudness level (PLL) (ref. 1), and perceived noise level (PNL) (ref. 2), with discrete frequency or duration corrections.

- It was ascertained that the measurement procedure applies to the flyover noise of both the treated and untreated airplanes.

- The change of annoyance with change in noise level of aircraft flyovers was assessed as a function of noise-reduction measuring scales. This evaluation is commonly expressed in statements such as "halving or doubling the effect on a community can be expected by reducing flyover noise by 'X' number of units."

- The rating method applied would allow the judges to evaluate all airplane flyover noise that occurred so that flyovers not part of the experiment would contribute to the data pool and the judges' experience would be less artificial.

- Data were collected that would permit comparing results from previous laboratory studies and those from the present field-testing experiment. Agreement between the two approaches would provide reassurance as to the adequacy and validity of the results.

- A means was provided for evaluating the relationship between persons, attitudes toward noise in general, and ratings of flyover noise.

The experiment was conducted at the Moses Lake, Washington, airport where 180 persons rated airplane flyover noise from the treated and untreated airplanes. This approach to investigating man's response to actual flyover noise was pioneered by investigators at the Farnborough Air Shows (refs. 3 and 4) and has also been used previously by U.S. investigators (ref. 5).

As indicated previously, the flight tests were carried out in two parts. In the first part, conventional noise rating approaches were used in which measurement of noise reduction was based on analysis of acoustic physical parameters; the second part dealt with man's subjective reaction to the noise reduction achieved. Volume IV, "Flightworthy Nacelle Development" gives the results from the first part; this volume describes results from the second.

The Boeing Company wishes to express its appreciation to S. S. Stevens, Head, Laboratory of Psychophysics, Harvard University, who served as the consultant to the program. His

experience searching for and establishing functional relationships between man's response and acoustic energy directed a course to follow and discreetly and tactfully kept us on it.

SYMBOLS

df	degrees of freedom
EPNdB	unit of effective perceived noise level
EPNL	effective perceived noise level, EPNdB
F	Snedecor's F test, i.e., the variance ratio distribution
Hz	hertz, cycles per second
MS	mean square
noy	unit of subjective noisiness
p	probability
PNdB	unit of perceived noise level
PLL	perceived loudness level
PNL	perceived noise level, PNdB
r	product-moment coefficient of correlation
sone	unit of subjective loudness
SS	sum of squares
USASI noise	random noise rising at 6 dB per octave, peaking at roughly 250 Hz, and falling off at 3 dB per octave (ref. 29)

TEST DESIGN

To collect data concerning the problem at hand, it was necessary to fly treated and untreated airplanes over a selected sample of the community. These people or "judges" were placed in the areas of interest, e.g., under the approach path where the maximum noise reduction was measured and at sideline locations from this position. For realism, the people

had the opportunity of hearing the noise both indoors and outdoors, since this would occur in the real-life situation. If the airplanes were flown under real flight conditions, the chosen airport location for the subjects would restrict the study to approach conditions only. Consequently, to ensure a well-rounded investigation, the airplanes were flown to simulate take-off and cutback operations as well as approach.

Psychophysical Techniques

Having discussed briefly how the airplanes were flown and where the observers were positioned, it is appropriate to discuss how the observers expressed their opinions concerning the airplane noises. Two main techniques were used:

- Constant stimulus differences
- Magnitude estimation

Constant stimulus differences technique.—The constant stimulus differences technique (sometimes called the "Method of Pair Comparisons") requires the listeners to decide which member of a pair of noises is more annoying. Several pairs can be presented with different separations in level. When 50 percent of the group of judges say one noise is more annoying than the others, this technique has provided all the information it can, that is, that the two noises were equally annoying when they were presented at a particular separation in level. If the separation between the noise levels is increased from this equally annoying point, no information on how far they are apart on a subjective scale can be gleaned from the judges' responses. The only conclusion possible is that the annoyance quality of each noise is different and that this difference can be detected by a certain percentage of the exposed population. If the judges were exposed to a pair of flyovers in which a treated airplane was flown with an untreated airplane under identical operating conditions (i.e., a 15-dB difference between noise levels at approach), the only conclusion could be that almost 100 percent of a group under the flightpath at 1 n. mi. from threshold could detect that they were different, not, how much different they were.

Magnitude estimation technique.—If more than an equally annoying point for two sounds is required, then another technique, such as magnitude estimation, must be used. In one variation of the magnitude estimation method, judges are given a standard sound that is arbitrarily assigned some number of units of annoyance, 10 for example. If a subsequent sound were evaluated as being twice as annoying as the standard, the judges would assign to it a value of 20 units. Now, if the sounds presented are different in level, this level difference can be transformed into a statement in which the difference in subjective reactions is quantified, e.g., "the noise-reduction halves the subjective quality of annoyance." This is precisely the type of statement needed in evaluating the effectiveness of the nacelles for airplanes performing similar operations.

Hybrid technique.—If the aircraft are flown in pairs and each pair member is judged separately against a standard sound, then the subjective scores can be analyzed in two ways:

- As paired comparisons, by determing which of the airplane sounds was given a larger annoyance score by each judge

- As a conventional magnitude estimation experiment

From actual recordings of the noises, various engineering numbers can be extracted (i.e., perceived loudness level (PLL) and perceived noisiness level (PNL)) and the subjective data matched to these values for both techniques. Under these conditions, the following steps can be taken to realize the aims of the study.

- The noise evaluation procedures chosen as most valid are those that agree with the subjective assessment of the noises in both the magnitude estimation and the paired comparison analyses.

- Once these procedures have been determined, the way the subjective responses change with airplane noise level change can be established. Thus, rate of change of annoyance can be used to quantify measured noise reductions in terms of expected community responses.

Selected Approach

A broad view of the test design will be given here. Actual details of how this design was achieved under flight testing conditions can be found in the section "Testing Layout." Subjective opinions on airplane noise were collected by the hybrid scheme described earlier while the noises heard by the judges were recorded on magnetic tape. Listening stations, both indoors and outdoors, were positioned directly under the flightpath of the airplane (for maximum effect of suppression) and at various sideline distances (to evaluate the actual worth of the suppression as the noises propagate into a nearby community).

Housetrailers were used to provide the indoor situations and canopy tents for outdoors situations.

To establish the manner in which subjective opinion varied with airplane operation and noise levels, the test airplanes were flown in pairs simulating takeoff, takeoff with cutback, and approach. The flights covered a range of altitudes for each airplane to provide the required sound-level variations.

The technique developed to collect the subjective data was so flexible that any sound at any level could be included in the study. The sound from jet airplane traffic using the test airport on an unscheduled basis was recorded and rated by the judges. Also, simple noises (e.g., broadband electronic noise) were presented to the judges by loudspeakers; both additional sources were included in the magnitude estimation analysis.

Simple loudspeaker noise was used throughout the study for several reasons, the most important being:

- The standard sound against which all the other test sounds are rated could be presented by loudspeakers at an easily controlled level and spectrum content.

- Rates of change of subjective opinion for various levels of loudspeaker noise have been well documented. Thus, the value obtained from this study could be compared with previous work as a check on the overall experiment. If agreement were found, then the judges were performing their loudspeaker noise judgments as instructed. Therefore, they also must be correctly judging the more complex flyover noises that were mixed in with the loudspeaker noise. This is a critical point. since there are scant data relating subjective responses to the direct magnitude of airplane flyover noise, particularly under field-test conditions.

  In addition, a means was provided, via an annoyance questionnaire, for evaluating in a cursory fashion the relationship between a judge's attitudes towards noise in general and the way he judged flyover noise.

TESTING LAYOUT

Listening Positions

The six listening positions, comprising three pairs of housetrailer and tent combinations, were set up 1 n. mi. from the runway approach threshold and assigned letters to aid identification, as indicated in figure 1. The listening positions were distributed this way to obtain a range of noise levels across the test area for each airplane flyover. A typical listening complex can be seen in figure 2. The outdoor judges can be seen near the center of the figure. The corner of the trailer is to the left.

The terrain in the area is flat and clear of large objects such as trees, buildings, etc. At the time of the test, the ground was covered with a sparse, short, weed-type vegetation.

Instrumentation

Details of the equipment used are presented in appendix A. Microphones with windscreens were set up in each listening position to record the noises as the judges heard them. One-third-octave-band analyses were completed in the laboratory after the test.

JUDGES

Selection

The six listening positions required 180 judges; 12 additional judges were used as backup. All 192 persons were hired through a state employment agency. Applicants were required to complete a 40-item annoyance questionnaire (see app. B). Prior to employment, the questionnarires were examined to determine the ability of the applicants to follow simple instructions. It was presumed that anyone who could not understand the instructions for the annoyance questionnaire would also have difficulty in understanding the nature of the noise-judgment task.

Assignment to a Listening Position

The main purpose of the annoyance questionnaire, with its 10 items relating to noise, was to ensure an unbiased assignment of judges to the six listening positions. This was achieved in the following manner:

- Each item was scored as 3, 2, 1, or 0.
- The judges were ranked by the sums of their scores across the 10 items, with the scores ranging from a maximum of 30 to a minimum of 0.
- The judges were then assigned to listening positions A through F in ranked order, as illustrated in table I.

In the distributions obtained, the groups were equal in their noise sensitivity, mean age, and education, as shown in table II.

Listening Task

The judges were instructed in their tasks by the test director who asked them to read the following instructions while they were voiced over the public address system in each listening position. "We are asking you to help us solve a problem concerned with noise: How annoying or disturbing are various kinds of sound when heard in your home? You will be asked to give a score for each sound. First, we will produce a sound whose noisiness score is 10. Use that sound as a standard, and judge each succeeding sound in relation to that standard. For example, if a sound seems *twice* as noisy as the standard, you will write 20 in the appropriate box on the answer sheet. If it seems only *one-quarter* as noisy, write 2.5. If it seems *three* times as noisy, write 30, and so on. Please try to judge each sound carefully, and give it a score that tells how strong the annoyance seems to you. There are no right or wrong answers. The important thing is to say how you rate each of the sounds."

After the judges had read the instructions, the test director made the following announcement over the loudspeaker system: "Your rating should be only your own opinion. The test will begin in a moment. Here is the sound that has a noisiness score of 10. Listen to it carefully."

Prior to presentation of each subsequent stimulus, the test director announced: "Rate the next sound in blank X on your answer sheets."

NOISES JUDGED

Types of Noise

Loudspeaker noise.—At the beginning of each listening session, a 4-sec USASI (United States of America Standards Institute) noise was presented via loudspeakers at a level of 90 PNdB at all six listening positions (ref. 5). This was the standard against which the judges were to compare all noises for that session. During the remainder of the session, at times when flyovers were not occurring, the 4-sec USASI noise was presented five more times at each of six sound levels.

The relative one-third-octave-band spectrum for USASI noise is shown in figure 3. The levels of noise presented, with their code letters, are given in table III.

The artificial noises were distributed throughout the flight test program to serve a twofold purpose:

- To provide a means of determining that the judges were adequately performing the task
- To keep the judges at their overall task of making annoyance judgments by presenting stimuli even during the unavoidable time delays between the flyover noises

Flyovers of treated and untreated airplanes.—One-third-octave-band spectra representative of the experimental flyovers are shown in figures 4 through 7. The effect of the treatment applied to the 707 airplane is evidenced by the difference between the treated and untreated airplanes under various operating conditions. The difference between the two spectra is particularly apparent for landing conditions (see figs. 4 and 5). These are spectra typical of the test day and have not been normalized to any "standard" conditions.

Unscheduled traffic.—Jet-powered airplanes that used the airport during the test were included in the noises presented to the listeners. This group of stimuli contained DC-8 and 727 airplanes. Typical recorded spectra are shown in figure 8.

Flyover Presentation Procedures

Both treated and untreated airplanes were flown in pairs or as specials as described below.

Pairs.—Pairs of level flyovers simulating approach and takeoff conditions were used. Table IV lists the pairs as planned for the 2 days of testing. For each condition, there were three pairs of flights in which the untreated airplane was flown at a given altitude and the treated airplane was flown at different altitudes on each run. The altitude variation changed the noise level of the treated airplane so that it was about 5 PNdB less than, equal to, or 5 PNdB greater than the level of the untreated airplane on successive pairs of flights. Each of the resulting four sets of three pairs (listed in table IV) was to be flown twice. On half the occasions, the judges first evaluated the untreated airplane and then the treated airplane; on the remaining occasions, the order of presentation for the pair was reversed. Since it was not possible to complete all of the program for the second day, some of the pairs listed for that day were not flown. Table IV shows the omitted pairs.

Specials.—Individual flyovers of both the untreated and treated airplanes were made at the same altitudes and power settings. These flyovers, referred to as specials, included simulated takeoffs and actual landings.

TEST PROGRAM

Each pair of treated and untreated airplanes and the specials were distributed in random order throughout the scheduled testing period, separated by approximately 8 min. The time between pair members was about 2 min. These separations were fixed mainly by the problems involved in flying the airplanes in a closed pattern around the airport. Loudspeaker noise was presented at random within the 8-min gap between scheduled flyovers, unless the time period was used by unscheduled traffic that merged into the flight pattern where possible.

Tables V and VI list the scheduled flights for sessions I and II, respectively. The expected sequence of flyover and loudspeaker noise can be seen in figures 9 and 10. Actual schedules for the two completed testing sessions are presented in tables VII and VIII. Included in the tables are the actual times of the events and photographically determined altitudes for the airplanes.

DATA ANALYSIS

Many methods exist for calculating the effect of noise on man; 18 of them were evaluated in this study.

Engineering Calculation Procedures Evaluated

There were 18 separate calculation procedures evaluated. The basis for nine of them was the widely used PNL scale. The remaining nine were based on S. S. Stevens' perceived loudness level (Mark VI) (PLL) from which the PNL approach was originally derived. In addition, two different tone correction methods using two different methods for identifying the tone were applied to each basic procedure. Finally, all tone-corrected procedures were corrected for duration per Federal Aviation Regulations part 36 (ref. 6).

Analysis Techniques

The experiment was designed and completed in a manner that allows two basic analysis techniques to be applied. One technique stems from the magnitude estimation method of rating the noise, while the second technique is based on equally annoying point solutions derived from the pairs of flights (method of constant stimulus differences). Both techniques provide information relevant to the selection of the most valid or appropriate engineering calculation procedure and, in this sense, supplement one another. If both techniques point to the same engineering calculation procedure, confidence in using that procedure for measuring noise reduction is enhanced. However, the magnitude estimation technique supplies additional information not provided by the method of constant stimulus differences (pairs) in that it quantifies rate of change of subjective response as a function of stimulus magnitude. This is a definite advantage in that the method of constant stimulus differences loses such detail when the subjective response data are necessarily classified in the coarse groups of greater or lesser annoyance.

Magnitude estimation.—The magnitude estimation method, refined by S. S. Stevens (refs. 7 and 8), has been used widely as a method of relating human response to a physical stimulus. Data from many studies indicate that the relationship between sensation and the physical stimulus is a power function (ref. 7, p. 166). This relationship may be written:

$$\psi = kI^n$$

where ψ = subjective response
I = stimulus intensity
k = constant of proportionality
n = constant exponent

If the intensity is expressed in decibels, then the equation after rearranging becomes:

$$\log_{10} \psi = \frac{n}{10} \times \mathrm{dB} + \text{constant}$$

Consequently, a log-log plot of subjective response versus stimulus power gives a linear relation with a slope of n/10. The quantity n has been determined experimentally for many stimuli. For noise in particular it has the approximate value of 0.3.

Constant stimulus difference.—The premise and conclusion of the constant stimulus difference approach is that, if two different sounds are judged equally annoying, an acceptable procedure for calculating subjective response should assign identical real numbers to both sounds.

In the present study, there were closely flown pairs of airplanes to which the judges assigned numbers proportional to the noise produced. The two numbers given for each pair by each judge were then separated into the categories of greater or lesser annoyance for the treated over the untreated airplane. The equally annoying situation was established when 50 percent of a group of judges stated that the treated airplane was more annoying than the untreated. An ideal engineering calculation procedure would give a zero-noise-level difference at this point.

Figure 11 shows an imaginary case of good agreement between the subjective judgments and the calculation procedure since the discrepancy is less than 1 PNdB. All 18 procedures were evaluated by using the available sets of pairs.

RESULTS AND DISCUSSION

The results presented in this section are in the six separate categories listed below. The first four are directly related to the primary aim of the subjective evaluation experiment; the fifth provides a link between the two parts of the flight test phase; and the sixth offers an additional analysis of the responses to the annoyance questionnaire described in appendix B.

- Judgments of loudspeaker noise
- Relationship between flyover annoyance judgments and selected engineering calculation procedures
- Evaluation of engineering calculation procedures using pair data
- Relationships based on casual flyovers
- Measured differences between treated and untreated airplanes
- Noise sensitivity and magnitude estimations

When the two general types of noises presented (loudspeaker and flyover noise) are considered, annoyance ratings for loudspeaker noise should be simpler and easier to make. Only level was varied for the loudspeaker noise, while level, spectra, and time pattern were varied for the flyover noises. Consequently, results based on judgments of loudspeaker noise should, if the judges are adequately performing the task, be comparable to results from other experiments using broadband and artificial noise. In addition, findings from these

results were to serve as a base for evaluating the results involving the much more complicated flyover noises. The results of judgments of the loudspeaker noises show convincingly that the judges were performing the task adequately and in a manner consistent with findings from comparable experiments.

Two indices were used both for evaluating the calculation procedures and for comparing the results based on annoyance judgments of flyover noise with those based on only loudspeaker noise.

1) Product-moment coefficient of correlation (r)

2) Rate of change of annoyance as a function of a particular engineering calculation procedure

The product-moment coefficient of correlation (r) is a ratio that expresses the extent to which linear changes in one variable are dependent on linear changes in a second variable; "r" ranges from 0.00 for no-relationship variables to 1.00 (perfect fit) for positive relationships. Rate of change of annoyance provides a measure of the effect on persons of increasing or decreasing noise levels (e.g., What is the expected quantitative effect on a community if noise level is reduced by 15 PNdB?).

There is already high confidence that the judges are proficient in making annoyance judgments of less complex noises. Therefore, differences in the two indices for results based on flyover noise versus those based on loudspeaker noise will be attributed to the considerably greater difficulty of rating noise as complex as that obtained from airplane flyovers. Comparison of the two kinds of noises on the basis of the two indices did indeed show differences that support the interpretation that persons make less precise or less certain evaluations of flyover noise than they do of loudspeaker noise. Differences in results for the two general types of noises are tentatively understood, and there is evidence from both sets of data that the judges were performing adequately.

The third results category involved evaluation of engineering calculation procedures using pair data. Each of the 18 engineering calculation procedures was evaluated by determining the difference between the treated and untreated airplane noises at the point that judges rated the two noises as being equally annoying. The aim of this analysis was to determine the extent of consistency with the previous approach using the product-moment coefficient of correlation. Results from the two approaches were consistent.

Results based on flyover noises from jet airplanes routinely using the airport were also obtained. Again, the relationships based on casual flyovers was generally consistent with those obtained from the first three results categories; the results among the four sets of data are essentially consistent.

The fifth results category provides the link between the two parts of the flight test phase. Since a different untreated airplane was used for the subjective experiments than was

used in the first part of the flight testing program, where the aim was to obtain a distribution of measurements, it was necessary to determine if measured differences for the two parts of the flight test program were comparable. Establishing comparability allows application of the results from the subjective reaction experiment to the measured differences obtained in that part of the flight test program where only differences in acoustical treatment were examined.

The last results category, "noise sensitivity and magnitude estimation," is not directly related to the main aim of the experiment. However, it does provide an additional analysis of the judges' responses to the annoyance questionnaire (app. B) and is thus directed to general problems and methodology of investigating human response to noise situations.

The section ends with a general discussion of the finding that corrections to basic procedures do not improve relationships and some comments concerning the problem of establishing an unbiased rate of change of annoyance.

Judgments of Loudspeaker Noise

Subjective responses are plotted as a function of both PNL and PLL in figures 12 and 13 where the judges' scores have been transformed into means and plotted on a log basis to match the log basis of PNL and PLL. To provide a means of checking on the consistency of the judgments, results for each listening position and for the two sessions are presented separately. The least-square lines are also shown. Using the product-moment coefficient of correlation (r) (ref. 9) as a measure of goodness of linear fit, there is no difference between the correlations based on PNL or PLL except in the third significant figure (fig. 14). The high and consistent (among listening positions and sessions) relationships between the judgments and the two calculation procedures are readily apparent from an examination of figure 14; the product-moment correlations range from 0.990 to 0.999 for PNL and from 0.987 to 0.999 for PLL.

Rates of change of annoyance.—Before presenting results for the rates of change of annoyance as a function of PNL and PLL, comments involving interpretation of this concept are presented, beginning with the following:

- Subjective response (magnitude estimation) is proportional to acoustic energy raised to a power (ref. 7).

- In log-log coordinates, the relationship between subjective response and acoustic energy is linear and represented by a straight line. The plots of figures 12 and 13 are typical examples.

- The slope of the line corresponds to the exponent of the power function. For common logarithms, 10 times the slope is equal to the exponent of the power function.

- The currently accepted value of the exponent is 0.3 (ref. 7). This value is derived from the finding that a 10-dB increase in acoustic energy results in a doubling of subjective response (ref. 7), provided that the spectrum shape remains constant as level is varied.

- The PNL calculation procedure assumes the same rate of change of annoyance or noisiness as was originally derived for loudness and PLL (ref. 10, p. 1424).

Using data from the current study, two main comparisons can be made: (1) for the rates of change of annoyance obtained from the various listening positions and (2) for the two sessions. All slope values obtained can be compared to the currently accepted exponent (0.3), and the rates of change of the two basic procedures (PNL and PLL) can be compared. Figure 15 shows a marked difference between results for the two calculation procedures. Just a cursory inspection of figure 15 reveals that the rate of change of annoyance is consistently greater for PLL than for PNL. This is due to the fact that, for the sound pressure levels of artificial noises presented, the PNL calculation method produces a greater range of numerical values than the PLL calculation method. Figure 16 uses the results from listening position B to further illustrate this fact. Note that, for lower levels of PNL (65 to 75 PNdB), PLL is greater; for higher levels of PNL (85 to 95 PNdB), PLL is less than PNL. Hence, there is a consistently greater range for PNL. Table IX gives the differences in range for the two calculation procedures and percent decreases in PNL slopes across listening positions for both sessions. The decrease in rate of change of annoyance varies from a low of 11.4 to a high of 20.0 percent. The explanation for this basic difference between the two calculation procedures is presented in appendix C.

Before returning to a discussion of the absolute values obtained for rates of change of annoyance, comment is required concerning the source of 0.3 as the value for rate of change and concerning the use of PNL and PLL as frequency dependent measures of acoustic energy (as opposed to overall sound pressure level, for example). The value of 0.3 as the exponent was selected as a result of much analytic work and many empirical studies using a variety of psychophysical techniques (ref. 11). Consequently, there is little expectation that the present experiment would exactly duplicate a "best" value obtained from a series of diverse experiments.

Both PLL and PNL have been used widely as substitutes for measures of acoustic energy in evaluating human response to airplane noise (refs. 12, 13, and 14). However, the PLL procedure includes a second-order effect called the "midlevel bulge" (ref. 1). Consequently, the rate of change of subjective response with noise was expected to be greater for the PLL procedure than for PNL, and the experimental value for the slope for PNL should be closer to the established value of 0.3. Therefore, it is only necessary to compare the rates of change for PNL with this established value to check the validity of this study. To assess noise reduction, however, either unit is applicable, provided that the correlation between the unit and the subjective responses remains satisfactorily high.

Examination of rates using PNL (see figure 15) shows that all values obtained are higher than the established one of 0.3. The rates of change of annoyance from session I vary from 0.33 to 0.39 with a mean value of 0.36. For session II, they range from 0.35 to 0.40 with a mean of 0.38. Although they are higher than the established value of 0.3, the slopes obtained are comparable to results from studies using the same experimental approach and psychophysical method. For example, a recent study (ref. 15) involving about the same range of acoustical energy (65 to 100 dB), and using magnitude estimation, obtained a 0.37 value for rate of change.

Implications of this experiment.—The essential conclusion pertinent to the present experiment is that the judges at all listening positions were, on the average, adequately performing their task; judgments of the changes in level of artificial noise monotonically increased in a consistent manner. This finding permits and supports the expectation that the judges can make evaluations of the flyovers in a similarly consistent manner.

In addition, a value for rate of change of annoyance was established for a particular group of persons responding to broadband artificial noise. This value is to be used as a comparison measure for these same subjects when judgments of the more complicated airplane flyover noises are evaluated.

Relationship Between Flyover Annoyance Judgments and Selected Engineering Calculation Procedures

As mentioned previously, 18 calculation procedures were to be applied to the flyover recording with the aim of relating these results to the magnitude estimations of the flyovers. Table X presents the symbols used in identifying the procedures plus a description of each. Procedure 1 is the familiar perceived noise level (PNL) (ref. 2), while procedures 2 through 9 are variants of PNL emphasizing tone and duration corrections to PNL. Procedure 10 is perceived loudness level (PLL, Stevens Mark VI) (ref. 1), and procedures 11 through 18 involve tone and duration corrections to PLL. PNL and PLL were selected as the basic procedures due to the facts that PNL has been widely applied to airplane flyover noise and is basically PLL with a slight modification (ref. 10). Procedure 6 of table X is the effective perceived noise level (EPNL) currently in use for FAA aircraft noise certification.

As with the subjective evaluations of the artificial noise, the product-moment coefficient of correlation (ref. 9), is used as a measure of the relationship between the judges' judgments and the 18 engineering calculation procedures of table X. Coefficients of correlation are presented in figures 17 through 22 for the magnitude estimations versus each of the 18 calculation procedures. Figure 17 gives results from session I based on judgments of flyover noise from both the treated and untreated airplanes. The correlations are satisfactorily high for all of the procedures; for example, the PNL correlation is 0.94 while the result for PLL is 0.93. This slight difference is attributed to error and is in no manner significant from a statistical or applied point of view. The results show that none of the tone-correction approaches improves the relationships when applied individually or in

combination with the noise certification duration approach (fig. 17 and ref. 6). For both PNL and PLL, the product-moment correlations are all slightly decreased when either tone or tone and duration corrections are applied to the basic calculation procedures.

Results from session II, which are also based on the judgments of flyover noise from both the treated and untreated airplanes, are given in figure 18; the relative positions of the 18 calculation procedures is strikingly similar to those of session I. The coefficient of correlation for PNL is 0.91 while it is 0.90 for PLL. Again, tone corrections or tone and duration corrections slightly degrade the relationships. In this respect, results from sessions I and II are consistent.

Figures 19 and 20 show results for sessions I and II but from judgments of the treated airplane only. Again, the correlations are satisfactorily high in that, for session I, the PNL correlation is 0.95 while the one for PLL is 0.94. Results for session II provided slightly lower relationships in that the correlations were 0.92 and 0.90 for PNL and PLL, respectively. However, there is high consistency for the pattern of results between the two sessions. For both sessions, all tone correction approaches tend to improve extent of agreement, while combined tone and duration corrections degrade the extent of agreement.

Turning to results for both sessions, based on judgments of flyover noise for only the untreated airplane, the correlations remain high, but the consistency between sessions for the pattern of results among the calculation procedures is not as striking as that for the treated airplane. For session I, the correlation for PNL is 0.94 and for PLL is 0.93; for session II, a correlation of 0.91 is found for PNL and 0.90 for PLL. Figures 21 and 22 show the results based on judgments for only the untreated airplane. For session I, tone corrections for either basic procedure leave all the correlations virtually unchanged, while tone and duration correction in combination tend to slightly improve the coefficient of correlations. For session II, it is clear (fig. 22) that all tone-correction approaches somewhat reduce the correlations, while tone and duration corrections in combination can lead to slight improvements.

Rates of change of annoyance.—Rates of change based on judgments of both the treated and untreated airplanes are given in figure 23. Note that PLL consistently shows a higher rate of change of annoyance than does PNL for judgments of flyover noise, just as was found for the judgments of the artificial noise. The explanation (see app. C) for this difference is identical to that proposed for the difference found for artificial noise; for both the treated and untreated airplanes, the range of PNL values assigned is greater than that assigned to the flyover noise by PLL.

The treated and untreated airplanes are compared for rate of change of annoyance in figures 24 and 25. For session I, PNL rate of change for the treated airplane is 0.027, while it is 0.026 for the untreated airplane. The findings for session II are comparable in that the value for PNL is 0.025 for the treated and 0.023 for the untreated airplane. These values are only slightly different from those found by combining results from both airplanes for the individual sessions; the PNL rate of change of annoyance for session I is 0.026, while it is 0.024 for session II. These results lead to the conclusion that annoyance caused by the treated and untreated airplanes increases at approximately the same rate.

However, when comparing these rates of change of annoyance of airplane flyover noise to those obtained from the judgments of artificial noises, the differences are striking. If the mean across sessions is obtained for the artificial noises, the value is 0.037; the mean across both sessions for both airplanes is 0.025. This is a reduction for the airplane noise of some 32 percent in rate of change of annoyance. There is a strong possiblility that this marked reduction is due to a regression effect discussed by Stevens (ref. 16). It may be that judges do make less certain judgments of the more complicated airplane noise signals. To have confidence that the "regression effect" does explain this slower than expected rate of change of annoyance, a similar study using magnitude production as the psychophysical technique would be required.

Figures 23 through 25 show another result that has implications for noise-reduction applications. Note that, when tone and duration corrections are applied to either PNL or PLL, the rate of change of annoyance is always decreased. In effect, the EPNdB scale has been stretched and 1 PNdB no longer equals 1 EPNdB. Using the mean PNL value of 0.025 across both sessions and for both airplanes and comparing it with the 0.022 value obtained for EPNL, the decrease in rate of change of annoyance is 12 percent for the EPNL scale.

Implications of this experiment.—The finding that the tone or tone and duration corrections do not improve the relationships between the calculation procedures and the judges' judgments suggests that obtained differences between the two airplanes can be safely evaluated on the basis of PNL or PLL. That there are only slight differences for measures of linear goodness of fit and rates of change of annoyance when applied individually to the treated and untreated airplanes supports the idea that the calculation procedures work equally well for both airplanes. As an example of the kinds of plots obtained, figures 26 and 27 show results based on the EPNL calculation procedure (calculation procedure 6 of table X).

Evaluation of Engineering Calculation Procedures Using Pair Data

The strategy basic to flying the two airplanes in pairs was aimed at establishing equally annoying point solutions as a means of checking on results based on a correlation approach. The results from the earlier section, "Relationship of Flyover Annoyance Judgments to Selected Engineering Calculation Procedures," show that the basic calculation procedures are not improved by the tone or tone and duration corrections; if anything, the corrections tend to degrade the relationship between the judgments and the corrected procedures, particularly when the treated and untreated airplanes are evaluated together. Then the question put to the data of this section is: Do equally annoying point solutions support the results based on a correlational strategy?

Before presenting results from the judgments of flyover pairs, it is necessary to emphasize that these data are curtailed. There are two reasons for this. First, because all the scheduled flights were not completed, some of the pair sets were not completed; second,

changes in airplane altitude did not produce consistent changes in the noise levels at the 1000- and 1500-ft sideline listening positions. Figures 28, 29, and 30 illustrate this point. Figure 28 shows the relationship between the PNL calculation procedure and altitude for the treated airplane directly under the flightpath (listening position A). As expected, PNL decreased as altitude increased and the relationship between the two measures is quite satisfactory—product-moment coefficient of correlation (r) is -0.995. At listening positions B and C, the relationship between altitude and PNL for the same flyovers is quite inconsistent as shown by the plots of figures 29 and 30; for listening position C, the relationship is, if anything, slightly positive as opposed to the expected negative relationship. As previous experience has shown, it is extremely difficult to obtain reliable sideline measures of flyover noise because there are several interacting variables that affect the results. For example, one investigation shows that atmosphere and terrain effects at the 1500-ft sideline distance can produce a variability of ± 10 dB for high-frequency flyover noise (ref. 17). This loss of data did not affect the magnitude estimation part of the study.

Due to this curtailment of data for flyover pair results, each of the 18 engineering calculation procedures was evaluated on the basis of eight sets of flyover pairs. Figure 31 gives an example of how the equally annoying point solutions were obtained. The percent that the treated was judged more annoying than the untreated airplane is plotted against the difference, based on a particular calculation procedure, between the two airplanes. For example, for pair 5 of figure 31, 45 percent of the judges found the treated more annoying than the untreated; the difference between the two airplanes (treated less untreated) is -0.64 PNdB; when EPNdB is evaluated, the difference is -2.68 EPNdB. Best fitting lines were then calculated and equal-annoyance points determined. Based on the set of pairs of figure 31, the results for PNL are that flyover noises from the two airplanes are equally annoying when the treated airplane is 1.4 PNdB less than that of the untreated airplane; the results for EPNL are that the noises are equally annoying when the treated airplane is 2.1 EPNdB less than that of the untreated airplane.

Table XI provides summary data for the basic engineering calculation procedures plus results from correcting the procedures using the tone and duration corrections according to the current certification approach (ref. 6). Correcting the basic procedures neither improves the mean of the equally annoying point predictions nor reduces the range of the predictions; results based on tone corrections only were significantly less accurate than those based on a combination correction, so they are not considered. In conclusion, the results using the pair strategy support those obtained from the correlation approach. The basic engineering calculation procedures are not improved by the various corrections.

Relationships Based on Casual Flyovers

One of the advantages of obtaining noise ratings for individual flyovers was that evaluations of casual flyovers could be made. Judgments and recordings for all listening positions were obtained for seven Boeing 727 flyovers during session II. Spectra for two of the flyovers are shown in figure 8. Because there were six listening positions, relationships

between the various engineering calculation procedures and the magnitude estimations are based on 42 data points. Figure 32 shows the product-moment coefficients of correlation for the 18 calculation procedures of this study. As for the correlations based on the experimental flyovers, these are satisfactorily high. Again, PNL is slightly higher than PLL (0.93 versus 0.91) but not significantly higher. Tone corrections do not improve either basic calculation procedure but tone and duration corrections do result in slight improvements; for example, the product-moment correlation is increased from 0.93 to 0.94 when PNL is corrected in accordance with noise certification procedures (ref. 6). An interesting point is that the correlation coefficient pattern for the 18 procedures is similar to the pattern found for the untreated airplane, figure 21. For both airplanes (untreated 707 and 727), combined tone and duration corrections do slightly improve the relationship between the judgments and the engineering calculation procedures.

Figure 33 shows data for rates of change of annoyance for the casual flyovers. In every manner, they are similar to those obtained for the experimental flyovers. The rate of change of annoyance for PNL is 0.023 and significantly less than the established value of 0.030. Rate of change of annoyance based on PLL is always greater than that based on PNL, and rates of change of annoyance are always reduced by a combined tone and duration correction. Consequently, it can be concluded that the calculation procedures are as applicable to the Boeing 727 as they are to the two 707-320B airplanes of this experiment.

Measured Difference Between Treated and Untreated Airplanes

The link between the subjective reaction part of the flight test program and that part of the flight test program that emphasized physical measurements only is provided by:

- Selecting the engineering calculation procedures that best relate to the judges' ratings of the flyover noises and establishing a rate of change function for these procedures.

- Determining if measured differences, using the selected engineering calculation procedure, are comparable for the two parts of the flight test program

The application of a particular engineering calculation procedure involves measurement of the two noises under identical conditions. There is always error of measurement regardless of the phenomenon under investigation, but the error can be unusually large when flyover noise is measured. As a consequence, a series of flyovers under identical conditions for each airplane is required; such an approach was used in this program and the results are reported in volume IV.

As suggested previously, the aim of the subjective response aspect of the flight test program was to ascertain that the engineering calculation procedures function as expected in the more realistic field-test environment and also to evaluate the differences due to nacelle

treatment from a community response point of view. Hence, no series of measurements under identical flight conditions for the two airplanes (treated versus untreated) is available from this part of the study. The photographic technique used to fix altitude did show both airplanes at the same altitude (355 ft) for the actual landings of session I (special flights 13 and 14). Noise reductions for the flyovers at the outdoors listening position can be examined for this pair and compared to the reductions obtained from the flight test program (vol. IV). Table XII gives the reductions (untreated less treated airplane) for three of the calculation procedures. The reduction of 15.5 PNdB directly under the flightpath (listening position D) is very close to the 16.0 PNdB achieved from a distribution of differences as reported in volume IV. Notice that, when PNL is corrected for only tone (tone correction of ref. 6), the reduction reaches 18 PNdB (tone-corrected) units, but because of the attenuation of the higher frequencies for the untreated airplane, differences are more rapidly reduced for the sideline listening positions. Reductions based on EPNL are not as large as those reported previously. A distribution of differences produced a reduction of 15.5 EPNdB, while the difference for this pair of actual landings is 13.2 EPNdB.

Since the treated airplane was flown at a range of altitudes so as to vary the noise level, it is possible, on the basis of a relationship between level and altitude, to extrapolate noise levels for the treated airplane to those flown by the untreated airplane. With this approach, actual values obtained for the untreated airplane can then be compared to those obtained by extrapolation. Results from this approach are considered tentative because the exact relationship between altitude and noise level is not linear; however, for the range of altitudes of interest (approximately 600 to 2000 ft), the relationship is closely approximated by a straight line.

Figure 34 shows the best fitting straight lines used to extrapolate noise levels for the treated airplane to those actually measured for the reference airplane. The results of this extrapolation for listening position A are given in table XIII; PNL is used as the calculation procedure as it shows a slightly higher relationship to the judges' evaluations of both airplanes. The mean of the differences for this indoors listening position is 11.9 PNdB with a standard deviation of 0.66. Since no indoors measurements were made for the physical part of the flight test program, there is no value to which this difference of 11.9 PNdB can be compared. It is less than the 15.5 or 16.0 PNdB obtained for the outdoors noise recordings because the structure produced more attenuation for the untreated airplane, where there was a greater emphasis on high-frequency components, than for the treated airplane. Table XIV shows similar data for listening position D. For outdoors recordings, the mean of the differences is 14.2 PNdB with a standard deviation of 1.20 PNdB. This compares favorably with the reduction of 13.2 PNdB at an altitude of 2000 ft for 5000-lb thrust obtained from a comparison of untreated and treated airplane results in figure 12, page 60, volume IV. In general, the reductions in noise for the subjective reaction portion are similar to those achieved for the physical measurement portion of the flight testing program. Therefore, it is concluded that the subjects were exposed to a representative range of levels and noise reductions.

Corrections to Basic Procedures Do Not Improve Relationships

There was particular interest in identifying a calculation procedure that was equally applicable to noise from both the treated and untreated airplanes. When applying the tone or tone and duration corrections to the basic engineering calculation procedures and relating these corrected procedures to noise judgments from both airplanes, there was a slight reduction in the relationship. Hence, it was concluded that no corrections were required to PNL or PLL for establishing the amount of noise reduction achieved. That the duration correction decreased the relationship is not surprising since, in many laboratories, agreement, even for simple noises, is tentative.

Three laboratory studies (refs. 2, 22, and 23) using broadband noise have produced results showing that duration effects are only apparent if judges are instructed to consider duration of the noise when making their ratings. Also, two of these studies (refs. 2 and 23) produced evidence that a duration effect is a function of the test method employed. A recent study did obtain duration effects for broadband noise without special instructions (ref. 24). Turning to previous experiments using flyover noise as signals, one study (ref. 24) has offered evidence supporting a duration correction, while three other experiments (refs. 13, 14, and 25) have shown that attempts to account for duration do not improve the calculation procedures. This study plus the other three makes four experiments where validity was not improved by including a duration correction to one experiment where durations did improve validity. Evidence to support increased validity when a correction for duration is included remains somewhat inconclusive. However, there is a slight, but in no way significant, tendency for tone and duration corrections to improve relationships for the untreated airplane; this same finding is supported by the results from the 727 airplane flyover noise.

The finding that corrections for tone do not improve the basic procedures is not consistent with results from other experiments (refs. 13 and 14). Careful scrutiny of the data plus the analysis based on the pair data lead to the conclusion that our judges were not responding as expected to the discrete frequency of the untreated airplane (see figs. 4 and 5). However, if the results are limited to the judgments for only the treated airplane, corrections for the discrete frequency do slightly improve the basic procedures (figs. 19 and 20). When considering only one aspect of this experiment, the findings are consistent with those from comparable experiments.

Establishing Unbiased Rate of Change of Annoyance

No firm conclusions can be reached in this area, but the results did point to some unexpected problems. The calculation procedure basic to evaluating man's response to noise is PLL; for the most part, the experimental work for PLL used broadband artificial noise and its components (ref. 26). Results from this study show marked differences for rates of change of annoyance for broadband artificial noise as opposed to flyover noise; rate of change is significantly greater for artificial noise than for flyover noise. Is this difference an artifact in the sense that judgments of the more complicated flyover noises are restricted by

the experimental method (a regression effect) (ref. 16), or is rate of change of annoyance actually slower for flyover noise? Two earlier experiments offer some evidence relative to this question.

Results from one experiment involving subjective evaluations of jet and piston engine flyover noises showed an average rate of change of annoyance of just under 13 PNdB to double the annoyance of the noise. Because this value was some 30 percent greater than the 10-dB rate for loudness, the conclusion reached was, ". . . and conceivably, therefore, annoyance increases more gradually than loudness as the intensity of the noise is increased. . . ." (ref. 27). The 13-PNdB rate is then in line with values obtained from this experiment for flyover noise judgments.

However, the conclusion that annoyance increases more gradually than loudness cannot be accepted because annoyance judgments of artificial noise (figs. 7 and 12, PNdB versus judgments) show rates of change comparable to those obtained from loudness judgments to artificial noise (ref. 16). The result of reference 27 (13 PNdB to double annoyance instead of 10 PNdB) is not due to a difference between the acoustic attributes of loudness and annoyance but is probably due to the fact that judgments of flyover noise are more complicated than those of artificial noise and thus show less certainty on the part of the judges. In fact, most experiments have shown insignificant differences between results pitting annoyance against loudness (see ref. 28).

Results from another earlier experiment showed a 16-PNdB increase was required to double annoyance (ref. 29); this value corresponds to an exponent of less than 0.2 in contrast to the 0.3 accepted value and is thus ". . . much larger than 10 PNdB for doubling noisiness originally assumed in developing the perceived-noise-level scale. . . ." (ref. 29). None of the rates of change in this experiment were as slow as that indicated by the 16 PNdB needed to double annoyance cited in reference 29 but they are reduced. (Session II results for the untreated airplane show the slowest rate—13.0 PNdB—for doubling annoyance, see fig. 25.)

There is agreement among the three studies but the pitfall to be avoided is acceptance of the results at their face value. There is a need to reemphasize that the results may be an artifact of the experimental technique and that the answer to the posed question remains uncertain. If the aim is to reduce the effect of flyover noise on the community by half, results based on evaluations of artificial broadband noise suggest that a reduction of approximately 10 PNdB is required, while those based on flyover noise point to a greater reduction. The problem is even more apparent for the EPNL approach as the duration correction always decreased the rate of change of annoyance. The basic scales have lost their original aim of relating auditory response to transformations of acoustic energy. Further efforts are required.

Noise Sensitivity and Magnitude Estimations

A research strategy aimed at understanding and predicting community response to noise involves social survey techniques where data based on questionnaires, interviews, and personality and attitude tests are related to various measures of noise levels. Reference 18 is an example of the social survey approach. There are questions concerning the interpretation of results from these approaches. For example, one proponent of these approaches has suggested that results based on laboratory studies would be different if subjects were selected on the basis of attitudinal variables (ref. 19). Also, results from an empirical research have shown that noise sensitivity as measured by a questionnaire predicts some of the variance of actual noise ratings (ref. 20). Perhaps results from laboratory and field-testing approaches would be different if these attitudinal variables were taken into account. Since there were 10 items in the annoyance questionnaire involving sensitivity to noise, it was possible to develop some data relevant to this problem.

Method.—Of the 40 items in the annoyance questionnaire, 10 related particularly to noise (see refs. 3 and 21 for use of questionnaire relative to airplane noise research). Judges rated all items on a four-point category scale, but only the responses to the 10 noise items were used for this part of the study. The four categories and their assigned numerical values were:

- Extremely annoying 3
- Moderately annoying 2
- Slightly annoying 1
- Not annoying 0

A measure of attitudes toward noise in general was obtained by summing the numerical values for the ratings of the 10 noise items. Thus, the maximum and minimum possible noise sensitivity scores were 30 and 0, respectively. Actual scores varied from a high of 27 to a low of 2. The 30 judges for each listening position were ranked according to their noise sensitivity score. So as to provide a fair test, the 10 judges with the highest noise sensitivity score were compared with the 10 judges with the lowest noise sensitivity scores. The measure used for comparing these high and low groups was the sum of the log magnitude estimations of the 23 flyovers of session I and the 34 flyovers of session II.

Results.—There was no difference for any of the comparisons at the six listening positions. Comparisons of mean scores based on the ratings of flyover judgments were the same for all high and low noise sensitivity groups. Tables XV and XVI give summaries of the analyses of variance based on individual sessions. Note for both sessions I and II that the F-ratios are less than one; this indicates that the means for the judgments to flyover noise are unusually similar for high and low noise sensitivity. As expected, both summaries show

highly significant differences between mean judgments from one listening position to another. This is, of course, due to the fact that the groups at the different positions were exposed to different noise levels, and their ratings reflect these differences in noise levels. Figure 35 shows the marked similarity of the mean magnitude estimations for high and low concern with noise, while figure 36 gives the mean differences across listening positions for high and low concern with general noises.

The conclusion based on these results is that, when noise ratings are made on a comparative basis or by matching of domains as opposed to category scaling, the judges' attitudes toward noise do not affect their judgments. The same conclusion does not necessarily follow if category scales had been used to rate the noises. It would be no surprise if persons who claim to be bothered by noise on a category scale test prior to a testing session would evaluate the actual noises in the same manner.

Category scaling and noise sensitivity.—This study did supply a small amount of evidence relevant to the finding that noise sensitivity measured by a questionnaire is related to noise evaluations using a category scale. At the end of each session, judges were asked to make a rating on a five-point scale as to the acceptability of all the noise experienced during that session. The scale and numerical values used in comparisons were:

_______ of no concern (1)

_______ acceptable (2)

_______ barely acceptable (3)

_______ unacceptable (4)

_______ completely unacceptable (5)

The mean of these ratings was also compared for the high and low noise sensitivity groups at each listening position and for both sessions. Figure 37 shows these results. There is a slight tendency for the high noise sensitivity groups to rate the total noise exposure as being less acceptable; this is particularly apparent for those at listening postiions A and D, directly under the flightpath. However, an analysis of variance (table XVII) shows a nonsignificant difference (0.25 P 0.10) based on the means from session I. If more than one category item were to have been used, it is expected that a reliable difference would have been found; the results are in the expected direction (9 out of 12 comparisons) and are thereby consistent with the results reported by Pearson and Hart (ref. 20).

It is extremely interesting that there was no difference in the use of the category scale from one listening position to another—particularly so, since there was a large difference in the noise levels at the various listening positions. For example, the peak noise for a flyover at position D was 118.8 PNdB, while the peak noise for a flyover at position C was 90.4 PNdB, a difference of 28.4 PNdB. The use of the category scale appears to depend on the persons using it and not on the differences in noise levels.

CONCLUSIONS

The strategy for the subjective reaction part of the flight test program was to collect sets of data that not only contributed to the main aim of the study (. . . determine if the measured differences found in the first part of the flight test program are perceived by a sample of persons from the community . . .), but also contributed to the broad problem of assessing man's response to airplane noise.

- Although all of the 18 engineering calculation procedures were adequate, PNL and PLL had a slightly higher linear relationship to the judges' ratings of the flyover noises. Therefore, it is concluded that they accurately quantify the measured differences between the treated and untreated airplanes.

- Results of the study also led to the conclusion that PNL and PLL applied equally well to both treated and untreated airplane noise. Relationships between these two units and the judges' ratings were again somewhat higher than those for the other calculation procedures, and rates of change of annoyance for the two airplanes were comparable.

- The magnitude estimation method permitted obtaining rates of change of annoyance as a function of any particular calculation procedure. Results show that the rate of change of annoyance caused by flyover noise is significantly slower than that caused by broadband loudspeaker noise. It was tentatively concluded that this result was due to the more difficult task of judging complex flyover signals where spectra, time pattern, and level are all varied.

- The simplicity and flexibility of the experimental method allowed ratings to be obtained for flyovers not part of the experiment (casual flyovers). Results based on these ratings were in general agreement with those obtained for the experimental flyovers.

- Comparisons of results of this and previous studies using both broadband and flyover noise signals led to the conclusion that the judges in this study were rating the noises in a manner comparable to judges used in other studies.

- Since the relationships, across all listening positions, between the judges' noise judgments and PNL were satisfactorily high ($r = 0.94$ and 0.91), it is concluded that all groups, irrespective of listening position, were responding appropriately to the differences between listening position noise levels.

- Since there was no relationship between the judges' attitudes toward noise in general and their ratings of the flyover noises, it was concluded that the magnitude estimation method, which emphasizes matching auditory function with a measure of acoustic energy, is not affected by attitudes toward noise.

APPENDIX A
THE PHYSICAL SYSTEM—LAYOUT AND CALIBRATION

Introduction

Larson Air Force Base, situated near Moses Lake, Washington, is surrounded by relatively flat terrain of a semidesert nature. The test location, 1 n. mi. from the main runway threshold, was devoid of roads and electrical power. In this situation, a self-contained experimental facility was built for 180 judges who were to evaluate the relative annoyance of various types of sounds. The requirements of such a facility were that judges were to be exposed to airplane flyover noise and loudspeaker noise both indoors and outdoors.

Listening Complexes

Three listening complexes were established. One was directly under the approach flightpath for runway 32; the two others were located at sideline distances of 1000 feet and 1500 feet. Each complex was provided with toilet facilities and drinking water.

A complex consisted of a canopy tent for outdoor listening and a housetrailer divided into two rooms to simulate the indoor situation. Their relative positions are shown in figure 1.

Indoor Locations

Seating.—Thirty people were assigned to each indoor location, 15 persons to a room. All were seated facing the approaching airplane. Windows looking on to the flightpath were closed.

Sound source.—USASI noise was generated in each room by a base reflex cabinet speaker driven by a 100-W amplifier. The speaker was placed in the corner of the room facing the wall to provide maximum dispersion of the sound field. The sound distribution within the rooms was checked at 12 measuring positions defined in figure A-1. Figure A-2 shows the octave-band data obtained.

Measurement of sound field.—Altec 21BR150 condenser microphones fitted with windscreens were placed in the center of each room. The general microphone height was the average seat pan height plus 29 in., which meant that, indoors, the microphones were 47 in. above the floor. This placed them at the average ear height.

The cathode follower was a Boeing-built field-effect transistor amplifier capable of driving 900 ft of coaxial cable to a central recording van.

Outdoor Locations

Seating.—Two parallel rows of 15 people each sat under the canopy tents facing the loudspeakers. The seats of the row furthest away from the loudspeakers were on a 1-ft-high platform presenting a uniform sound field to all the listeners (see fig. A-3).

Four backup listeners were seated under each tent, two at each end of the front row. They were to take part in the experiment and replace any listeners that might drop out of the test. Their services were not required, however.

Sound source.—Three 250-W column speakers were placed 5 ft apart and 15 ft from the front of the platform. They were driven in parallel by a 300-W amplifier.

Measurement of sound field.—Two microphones were placed 4 ft on each side of the centerline and immediately in front of the platform. The average seat height in this location was 6 in. more than the inside locations, giving a microphone height of 53 in. The equipment arrangement for a typical complex is shown in figure A-4.

Power Supplies

Electrical power for each complex was supplied by Onan power units rated at 1.8 kW at 115 Vac, 60 Hz. These were located 200 ft from the tents in such a way as to place the housetrailer between the generators and the outside listeners.

Acoustical Ambient Conditions

Noise from the generators was just audible above the "quiet time" acoustical ambient in each outdoor position. The measured ambient shown in figure A-5 exhibited a peak at 125 Hz, which was attributed to the generators. However, the total ambient was about 30 PNdB below the minimum airplane noise recorded in the test (at the 1500-ft sideline position) and could be disregarded.

Because of attenuation by the trailers (see table A-I), the separation between the indoor ambient condition and the minimum flyover noise was reduced. Figure A-6 shows this separation to be 20 PNdB, which was still an acceptable margin.

Test Control Van

All noise generating and recording equipment was installed in a control van positioned some 500 ft from the central complex and 900 ft from the others. The test director controlled the test from this position. Electric power was supplied by a portable generator.

Communication System

Three communication systems were established:

- VHF radio between the acoustic van and the airplane spotter enabled the test director to intersperse the artificial noise presentations between the aircraft flyovers.

- Intercom (wire) between the acoustic van and the three listening complexes made communication possible between the director and the monitors at each complex without being overheard by the listeners.

- A public address system from the acoustic van to all complexes via the loudspeaker system was used to instruct the judges at the beginning of the test and to indicate prior to each noise presentation that a judgment would be required.

Artificial Noise

Artificial noise was presented to the judges over the loudspeakers. The noise source was an Allison 650-R white-noise generator working through an Allison 38 octave-band spectrum shaper and then into a pulse generator. The pulse generator provided a 4-sec-duration noise signal with an exponential rise and decay rate. No disturbing transients were audible when a noise pulse was presented in any listening position. The actual pulse shape is shown in Figure A-7.

Recording System

A 14-channel tape recorder was located in the acoustic van. Twelve FM channels were used for recording the data at a tape speed of 30 ips. The two remaining channels were used to record a time code and the voiced gain settings of each channel.

Calibration Techniques

Prior to and after the test, all equipment was checked against manufacturer's specifications. These are shown in table A-II.

The complete system of microphone, preamplifier, and recorder had a sensitivity range of 100 dB and a usable frequency response of 20 Hz to 15 kHz. This was more than adequate for the test noises, which had a range of 60 dB and required analysis only in the frequency range of 50 Hz to 10 kHz.

Obtaining a uniform sound field in the six rooms and three outside positions required careful adjustment of the frequency response of each sound source. Pink noise (equal sound pressure level per octave band) was used as the calibration spectrum in this case.

The required standard level of 90 PNdB in all positions needed an estimate of the absorption due to people in the inside positions. Fifteen local volunteers were seated in one of the listening rooms, and the spectrum shaper was adjusted to return the octave-band levels to their previous values for the empty rooms. Once uniformity of response was established, the spectrum shaper was adjusted to provide USASI noise figure A-8. The absorption determination was repeated. Table A-III gives the mean absorption values used in the calibration.

Detailed knowledge of the spectra established in each listening position, together with the experimentally determined absorption, allowed calculation of the overall sound pressure level required in an empty location to produce 90 PNdB with the judges in position. These calculated levels were the essence of the artificial noise calibration of the test facility.

The programmed 5-dB increments in artificial noise level were provided by a 10-turn precision potentiometer while monitoring the rms output voltage of the noise source on a B&K 2112 voltmeter. Eight 5-dB increments, set up with the voltmeter, gave a change in acoustic level of 40.2 dB, as monitored by the data microphones. This was equivalent to a PNL range of from 70 to 110.2 PNdB. Both accuracy and range were obviously better than system requirements since the indoor range required was 70 to 95 PNdB and the outdoor range was from 80 to 105 PNdB.

Before the test, each of the 12 microphone channels were calibrated at a 124.4-dB sound pressure level with a B&K 4220 pistonphone. The individual amplier gains were then adjusted to produce the required overall sound pressure levels for the standard sound in each listening position when monitored by the data microphones. Postcalibration of the microphone system was carried out to guard against gross sensitivity changes.

Performance of the artificial noise system can be judged from the presentation of the nominal 90-PNdB standard calculated from the measured spectra during the test with the subjects in position. Figure A-9 shows the mean standard for both sessions in the testing program across all listening positions.

Redundancy

A duplicate recording system was stored in the acoustic van to guard against the event of equipment failure.

In each complex, two microphone systems inside and out provided sufficient backup. In the event of a failure, data would be available from at least one microphone. Extra signal and microphone cables were run to each position in case some of the judges caused damage by walking on the cables.

Precalibrated loudspeaker and amplifier combinations were held in reserve as backup to the sound presentation system. As it happened, this was the only backup called upon. Position C had an amplifier failure 10 min before the arrival of the judges. The replacement system produced the required level with less than 0.5-dB error from the nominal.

The Boeing Company
Commercial Airplane Group
Seattle, Washington, August 1970

APPENDIX B
ANNOYANCE QUESTIONNAIRE

The annoyance questionnaire contains 10 items that solicited the judges' annoyance ratings for some hypothetical noise situations. Scores for the 10 items were used in assigning the judges to the six listening positions and in determining high and low concern with noise. The 10 items in the questionnaire are: 3, 7, 10, 15, 18, 22, 24, 28, 32, and 37.

Name ______________________________ Age __________
Male ____ Female ____________ Years of Schooling Completed ____________
Occupation ____
Do you believe that you have normal hearing? Yes _____ No _______
If answer is "No," please explain: ______________________________

Please rate each of the following situations as to amount of annoyance they produce for you. Use the following numbers of the various levels of annoyance:

3. . . . . . . .Extremely annoying
2. . . . . . . .Moderately annoying
1. . . . . . . .Slightly annoying
0. . . . . . . .Not annoying

For example, the situation:

Roaches in the kitchen cabinets (2) .

If you rate this situation as being "moderately annoying" for you, you would write "2" in the blank space.

1. A person in an automobile which I am driving telling me how to drive __________
2. To see an intoxicated woman __________
3. To hear water dripping from a tap __________
4. A public speaker who talks in a halting manner __________
5. To be laughed at __________
6. To see a person wearing dirty clothes __________
7. To hear a neighbor's radio, television, or phonograph playing loudly __________
8. A salesman trying to force me to buy something __________
9. A person monopolizing the conversation __________
10. To hear chalk squeaking on a blackboard __________
11. A person talking when he has a good deal of food in his mouth __________
12. The odor of bad breath __________
13. A person continually talking about his illness __________
14. To just miss a bus __________
15. To hear heavy traffic continually passing my house __________

16. To have to get off the pavement to pass some people who are taking up all the room ___________
17. To be in a poorly ventilated room ___________
18. To hear dogs barking or cats fighting when I am trying to go to sleep ___________
19. A dirty washbasin ___________
20. Flies ___________
21. To have to wait for a person who is late for an engagement ___________
22. To hear a low-flying jet pass overhead ___________
23. To see a person's nose running ___________
24. To hear a person snoring ___________
25. A person crowding in front of one instead of waiting his turn in line ___________
26. To see a man in need of a haircut or shave ___________
27. Not being served promptly in a shop ___________
28. To hear the prolonged crying of someone else's baby ___________
29. To see an untidy room ___________
30. To see a person at the table pour out his tea or coffee into the saucer and drink it from the saucer ___________
31. To be pushed when in a crowd ___________
32. To hear a pneumatic drill working outside my house ___________
33. To see or hear a child being harshly treated by an older person ___________
34. A person looking over my shoulder and reading the book or newspaper which I am reading ___________
35. To find some dirt in the food I am eating ___________
36. To be cut off on the telephone ___________
37. To hear the prolonged ringing of a telephone ___________
38. To be interrupted when I am talking ___________
39. A person continually trying to borrow some of my things ___________
40. To see or hear interference on the television or radio ___________

APPENDIX C
PNL VERSUS PLL AND RATE OF CHANGE OF ANNOYANCE

Relating the subjective response data to the two basic calculation procedures produces differing rates of change of annoyance for both the artificial noise and the flyover noises. The PNL procedure produces a slower rate of change than the PLL procedure. The "Results and Discussion" section shows that a "stretching" of the PNL scale accounts for this difference between the two scales. The aim of appendix C is to account for this unexpected scale stretching in PNL through examination of the basics of the two approaches.

Since the PNL scale is completely modeled on the PLL scale with the single exception that the equal-loudness contours were slightly modified to obtain equal-noisiness contour (ref. 10), attention was focused on differences between these two sets of curves. The most recent version of these two sets of curves (refs. 1 and 2) shows larger differences than those that existed when PNL was first proposed (ref. 10). The increase in difference between the two sets of curves is primarily due to changes in the equal-loudness contours; these changes attempted to reflect the findings that broadband noise increases more rapidly in loudness over the midlevel range for hearing; thus, the change was made to bring the PLL calculation procedure more in line with the behavior of the auditory system in the subjective evaluation of acoustic energy. This change, commonly known as the "midlevel bulge" (ref. 1), leads to different growth functions for the two procedures. Figure C-1 illustrates this difference for the 1-kHz frequency. For unusually low levels, approximately 0.10 and 0.11 Noy or Sone, band pressure level is greater for Sone (PLL) than for Noy (PLL); therefore, at this level, values for the PNL calculation procedure will be higher than those for the PLL procedure. The PLL curve very quickly crosses the PNL curve, and, for Noy and Sone values of about 0.11 to 10.00, the PLL procedure produces higher values than does the PNL calculation procedure. This explains the higher PLL values for the 70 to 80 PNdB range illustrated in figure 15. Figure C-2 shows plots of equal noisiness (Noy) and equal loudness (Sone) curves; again it is seen that, for most of the spectrum, larger Sone values than Noy values are required for identical band pressure levels at the midlevel range, while the reverse is found for sounds at the higher levels. As can be seen by comparing the two sets of curves of figure C-2, the actual difference between the two approaches depends on the spectrum and will to some extent vary with the noise spectra being evaluated.

As a means of further examining the difference for rate of change of annoyance of the two basic calculation procedures, the PNL and PLL calculation procedures were applied to a wide range, approximately 40 to 150 PNdB, of USASI noise. Figure 3 shows the spectrum for this broadband noise.

To transform the data to a form similar to that obtained for this study, the assumption was made that an increase of 10 dB in PNL resulted in a doubling of subjective magnitude. An arbitrary standard of 88.6 PNdB was assigned the subjective magnitude of 100. A plot for $\log_{10}$ (subjective response) against PNL under these conditions will be a straight line passing through the point 2,88.6. Now, for any study involving presentation of noises, the

subjective responses once collected are fixed. However, other calculation procedures can be applied to the noise spectrum. The data points will then be shifted along the physical axis by any differences in calculation procedures. This effect is shown in figure C-3. There we see that below 80 dB, PNL is less than PLL; above 80 dB, the situation is reversed.

For the range of levels of artificial noise used in this example (i.e., between 70 to 105 dB), the ratio of the rates of change of subjective response for PLL/PNL is 1.17. For the actual data collected in the study, the ratio was found to be 1.17 ± 0.01.

The situation would then be that a 10-dB increase in perceived noisiness would double the subjective magnitude, while such a doubling of sensation for perceived loudness would require a change of around 8.5 dB in perceived loudness level.

Clearly, the accepted value of 10 dB for doubling the sensation aroused by noise does not apply equally to the PNL and PLL calculation procedures.

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TABLE I.–SCHEME USED TO ASSIGN JUDGES TO LISTENING POSITIONS

Males			Females		
Rank	Score	Listening group	Rank	Score	Listening group
1	30	A	1	30	A
2	30	B	2	29	B
3	30	C	3	29	C
4	29	D	4	29	D
5	29	E	5	29	E
6	29	F	6	28	F
7	29	A	7	27	A
8	29	B	8	26	B
9	28	C	9	26	C
10	28	D	10	26	D
11	28	E	11	26	E
12	28	F	12	26	F
13	28	A	13	25	A
14	27	B	14	25	B
15	22	C	15	25	C
16	25	D	16	24	D
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
93	4	C	93	3	C
94	4	D	94	2	D
95	3	E	95	0	E
96	0	F	96	0	F

TABLE II.–DISTRIBUTION OF JUDGES BY AGE, SCHOOLING, AND NOISE SENSITIVITY

Category	Listening position						Overall
	A	B	C	D	E	F	
Age (range 18 to 67 years)							
Males	31.9	32.6	30.0	35.3	35.0	30.8	32.6
Females	30.6	33.5	34.1	34.1	34.9	29.9	32.9
Overall	31.3	33.1	32.0	34.7	34.9	30.4	32.7
Years of schooling (range 6 to 18 years)							
Males	13.4	14.1	12.7	13.5	13.5	13.2	13.4
Females	12.1	12.4	12.3	12.2	12.2	12.9	12.4
Overall	12.8	13.2	12.5	12.9	12.9	13.1	12.9
Noise sensitivity							
Score	15.9	15.7	14.3	14.5	15.4	15.1	----

TABLE III.–PRESENTATION LEVELS FOR USASI NOISE

Artificial noise code	Indoor PNL	Outdoor PNL
1u	70	80
2u	75	85
3u	80	90
4u	85	95
5u	90	100
6u	95	105

TABLE IV.– PAIRS[a] OF UNTREATED AND TREATED AIRPLANES

Airplane	First day		Second day					
	Simulated landings with 5000-lb thrust		Simulated landings with 5000-lb thrust		Simulated takeoffs with maximum thrust		Simulated takeoffs with cutback thrust	
	Altitude, ft	PNL, PNdB	Altitude, ft	PNL, PNdB	Altitude, ft	PNL, PNdB	Altitude, ft	PNL, PNdB
U	2000	99	2000	99	2300	108	3400	98
T	1150	94	1150	94	2100[b]	103	2100	93
	850	99	700[b]	99	1600[b]	108	1600[c]	98
	650	104	450	104	1100	113	1100[d]	103

[a]A pair of flights for a simulated landing or takeoff consists of the untreated airplane flown at the altitude listed at the head of the "altitude" column for that simulation and the treated airplane flown at one of the three altitudes listed for it in the same column. Each pair is flown twice, once with the untreated airplane first and the other time with the treated airplane first.

[b]Both flights of these pairs not flown.

[c]Flight with untreated airplane first not flown.

[d]Flight with treated airplane first not flown.

U = Untreated airplane
T = Treated airplane

TABLE V.–FLIGHT SCHEDULE (SESSION I)

Order	Pair or flight number	Airplane	Operation	Altitude, ft
1	8	U	A	390
2	2	T	SA	850
	2	U	SA	2000
3	7	T	A	390
4	3	T	SA	650
	3	U	SA	2000
5	5	U	SA	2000
	5	T	SA	850
6	1	T	SA	1150
	1	U	SA	2000
7	4	U	SA	2000
	4	T	SA	1150
8	6	U	SA	2000
	6	T	SA	650
9	9	U	CB	1000
10	10	T	CB	1000
11	11	U	STO	1000
12	12	T	STO	1000
13	13	U	A	355
14	14	T	A	355

A = Approach with 5000-lb thrust
STO = Simulated takeoff with maximum thrust
SA = Simulated approach with 5000-lb thrust
CB = Simulated takeoff with cutback thrust
U = Untreated airplane
T = Treated airplane

TABLE VI.–FLIGHT SCHEDULE (SESSION II)

Order	Pair or flight number	Airplane	Operation	Altitude, ft
1	20	U	A	390
2	11	U	STO	2300
	11	T	STO	1600
3	13	T	CB	2100
	13	U	CB	3400
4	4	U	SA	2000
	4	T	SA	1150
5	12	U	STO	2300
	12	T	STO	1100
6	14	T	CB	1600
	14	U	CB	3400
7	19	U	GS	390
8	24	T	GS	390
9	16	U	CB	3400
	16	T	CB	2100
10	3	T	SA	450
	3	U	SA	2000
11	18	T	CB	3400
	18	U	CB	1100
12	6	U	SA	2000
	6	T	SA	450
13	1	T	SA	1150
	1	U	SA	2000

A = Approach with 5000-lb thrust
STO = Simulated takeoff with maximum thrust
CB = Simulated takeoff with cutback thrust
SA = Simulated approach with 5000-lb thrust
U = Untreated airplane
T = Treated airplane

TABLE VII.–NOISE JUDGMENT SCHEDULE (SESSION I)

No.	Code	Notes	Time	No.	Code	Notes	Time
0	3u	Standard at 90 PNdB	2:40	27	(5)	U (altitude 2040 ft)	3:20
1	3u	90 PNdB		28	(5)	T (altitude 875 ft)	3:23
2	4u	95 PNdB		29	6u	105 PNdB	
3	1u	80 PNdB		30	2u	85 PNdB	
4	1u	80 PNdB		31	4u	95 PNdB	
5	(8)	U (special landing)	2:47	32	4u	95 PNdB	
6	1u	80 PNdB		33	(1)	T (altitude 1255 ft)	3:36
7	DC-8	No recording	2:48	34	(1)	U (altitude 1980 ft)	3:38
8	2u	85 PNdB		35	3u	90 PNdB	
9	6u	105 PNdB		36	1u	80 PNdB	
10	(2)	T (altitude 870 ft)	2:49	37	1u	80 PNdB	
11	(2)	U (altitude 2100 ft)	2:56	38	5u	100 PNdB	
12	4u	95 PNdB		39	6u	105 PNdB	
13	3u	90 PNdB		40	(4)	U (altitude 2100 ft)	3:44
14	6u	105 PNdB		41	(4)	T (altitude 1170 ft)	3:47
15	(7)	T (special landing)	2:59	42	3u	90 PNdB	
16	DC-8	Landing	3:05	43	5u	100 PNdB	
17	5u	100 PNdB		44	5u	100 PNdB	
18	2u	85 PNdB		45	3u	90 PNdB	
19	2u	85 PNdB		46	(6)	U (altitude 2180 ft)	3:54
20	(3)	T (altitude 640 ft)	3:11	47	(6)	T (altitude 710 ft)	3:56
21	(3)	U (altitude 2000 ft)	3:14	48	(9)	U (altitude 1235 ft)	4:02
22	DC-8	Landing	3:15	49	(10)	T (altitude 1050 ft)	4:03
23	6u	105 PNdB		50	(11)	U (altitude 1070 ft)	4:11
24	5u	100 PNdB		51	(12)	T (altitude 975 ft)	4:13
25	4u	95 PNdB		52	(13)	U (altitude 355 ft)	4:19
26	2u	85 PNdB		53	(14)	T (altitude of 355 ft)	4:20

Numbers with "u's" refer to USASI random noises (the numbers indicate relative level)
U = Untreated airplane
T = Treated airplane

TABLE VIII.—NOISE JUDGMENT SCHEDULE (SESSION II)

No.	Code	Notes	Time	No.	Code	Notes	Time
0	3u	Standard at 90 PNdB	9:08	33	(14)	U (altitude 3640 ft)	9:55
1	727	Landing	9:12	34	5u	100 PNdB	
2	3u	90 PNdB		35	6u	105 PNdB	
3	1u	80 PNdB		36	727	No recording	9:58
4	2u	85 PNdB		37	(19)	U (special landing)	10:01
5	3u	90 PNdB		38	(24)	T (special landing)	10:02
6	5u	100 PNdB		39	3u	90 PNdB	
7	(20)	U (special landing)	9:14	40	3u	90 PNdB	
8	1u	80 PNdB		41	4u	95 PNdB	
9	2u	85 PNdB		42	(16)	U (altitude 3675 ft)	10:07
10	727	Landing	9:21	43	(16)	T (altitude 2195 ft)	10:09
11	(11)	U (altitude 2375 ft)	9:23	44	2u	85 PNdB	
12	(11)	T (altitude 1625 ft)	9:25	45	5u	100 PNdB	
13	6u	105 PNdB		46	4u	95 PNdB	
14	727	Landing	9:26	47	727	Landing	10:16
15	5u	100 PNdB		48	(3)	T (altitude 495 ft)	10:17
16	(13)	T (altitude 2300 ft)	9:31	49	(3)	U (altitude 2185 ft)	10:20
17	(13)	U (altitude 3650 ft)	9:33	50	5u	100 PNdB	
18	727	Landing	9:35	51	3u	90 PNdB	
19	2u	85 PNdB		52	(18)	U (altitude 3575 ft)	10:24
20	6u	105 PNdB		53	(18)	T (altitude 1130 ft)	10:25
21	727	Landing	9:38	54	1u	80 PNdB	
22	(4)	U (altitude 2125 ft)	9:39	55	2u	85 PNdB	
23	(4)	T (altitude 1235 ft)	9:40	56	727	Landing	10:30
24	6u	105 PNdB		57	(6)	U (altitude 2100 ft)	10:32
25	4u	95 PNdB		58	(6)	T (altitude 390 ft)	10:34
26	727	No recording	9:44	59	727	No recording	10:35
27	(12)	U (altitude 2550 ft)	9:46	60	4u	95 PNdB	
28	(12)	T (altitude 1180 ft)	9:47	61	1u	80 PNdB	
29	6u	105 PNdB		62	(1)	T (altitude 1215 ft)	10:37
30	4u	95 PNdB		63	(1)	U (altitude 2190 ft)	10:41
31	1u	80 PNdB		64	727	Landing	10:42
32	(14)	T (altitude 1770 ft)	9:53				

Numbers with "u's" refer to USASI random noises (the numbers indicate relative level)
U = Untreated airplane
T = Treated airplane

TABLE IX.— DIFFERENCES IN RANGE FOR PNL AND PLL AND PERCENT DECREASES IN PNL SLOPE

Factor	Listening position					
	A	B	C	D	E	F
Session I						
PNL range less PLL range	3.73	3.78	3.06	2.48	3.35	2.76
Decrease in PNL slope, %	14.3	15.9	11.9	11.4	13.2	10.0
Session II						
PNL range less PLL range	3.17	4.46	4.38	3.24	3.18	3.58
Decrease in PNL slope, %	13.6	20.0	17.4	13.6	11.9	12.5

TABLE X.—SYMBOLS FOR IDENTIFYING ENGINEERING CALCULATION PROCEDURES

No.	Symbol	Description and reference
1	PNL	Familiar perceived noise level procedure
2	B_1	PNL corrected for tone according to FAR 36
3	B_2	PNL corrected for tone according to third revised draft of proposed FAA noise certification criterion (May 1, 1967); slope method used to identify tone
4	J_1	PNL corrected for tone according to FAR 36 but tone identified by four-band averaging technique
5	J_2	PNL corrected for tone according to third revised draft (3 of this table) but tone identified by four-band averaging technique
6	EB_1	Same as 2 but duration correction of FAR 36 applied; this is EPNL for FAA noise certification
7	EB_2	Same as 3 but FAR 36 duration correction added
8	EJ_1	Same as 4 but duration correction of FAR 36 added
9	EJ_2	Same as 5 but duration correction of FAR 36 added
10	PLL	Perceived loudness level (Stevens MarkVI)
11	B_1	Corrected PLL where corrections exactly match corrections applied to PNL for 2 through 9; e.g., B_1 (11) under PLL is PLL corrected for tone according to FAR 36
12	B_2	
13	J_1	
14	J_2	
15	EB_1	
16	EB_2	
17	EJ_1	
18	EJ_2	

TABLE XI.—SUMMARY OF EQUALLY ANNOYING POINT PREDICTIONS FOR CALCULATION PROCEDURES

Calculation procedure	Mean of predictions	Lowest and highest prediction
PNL	-1.95	-6.8 to +2.5
PLL	-0.49	-4.6 to +3.5
ET_1 PNL	-3.67	-9.1 to +1.4
ET_1 PLL	-1.98	-6.7 to +2.3

TABLE XII.– NOISE MEASUREMENT DIFFERENCES (UNTREATED LESS TREATED AIRPLANE–LANDING)

Calculation procedure	Listening position		
	D	E	F
PNL	15.5	12.2	11.0
B_1PNL	18.0	13.2	10.7
EB_1PNL (EPNL)	13.2	11.5	7.8

TABLE XIII.– NOISE MEASUREMENT DIFFERENCES (UNTREATED LESS PREDICTED VALUES OF TREATED AIRPLANE)–POSITION A (SESSION I)

Number of untreated airplane flyovers	Altitude of untreated airplane	PNL of untreated airplane	PNL prediction for treated airplane	Untreated less treated[a]
1	1980	86.21	73.78	12.43
2	2100	85.04	72.70	12.34
3	2000	84.36	73.60	10.76
4	2100	84.46	72.70	11.76
5	2040	84.93	73.24	11.69
6	2180	84.50	71.98	12.52

[a]Mean PNdB = 11.9; standard deviation = 0.66

TABLE XIV.—NOISE MEASUREMENT DIFFERENCES (UNTREATED LESS PREDICTED VALUES OF TREATED AIRPLANE)—POSITION D (SESSION I)

Number of untreated airplane flyovers	Altitude of airplane	PNL of untreated airplane	PNL prediction for treated airplane	Untreated less treated[a]
1	1980	95.46	81.63	13.83
2	2100	94.52	80.31	14.21
3	2000	95.97	81.41	14.56
4	2100	94.25	80.31	13.94
5	2040	93.42	80.97	12.45
6	2180	95.60	79.43	16.17

[a]Mean PNdB = 14.2; standard deviation = 1.20

TABLE XV.—SUMMARY OF ANALYSIS OF VARIANCE FOR FLYOVER NOISE RATINGS AS A FUNCTION OF NOISE SENSITIVITY AND LISTENING POSITION (SESSION I)

Source	SS	df	MS	F
Rows (noise sensitivity)	0.001	1	0.001	1
Columns (listening position)	7.629	5	1.5258	39.5592[a]
Interaction	0.159	5	0.0318	1
Error (within cells)	4.166	108	0.03857	———
Totals	11.955	119	———	———

[a]$p < 0.005$

TABLE XVI.—SUMMARY OF ANALYSIS OF VARIANCE FOR FLYOVER NOISE RATINGS AS A FUNCTION OF NOISE SENSITIVITY AND LISTENING POSITION (SESSION II)

Source	SS	df	MS	F
Rows (noise sensitivity)	0.003	1	0.003	1
Columns (listening position)	3.814	5	0.728	23.1643[a]
Interaction	0.042	5	0.0084	1
Error (within cells)	3.556	108	0.03293	———
Totals	7.415	119	———	———

[a]$p < 0.0005$

TABLE XVII.—SUMMARY OF ANALYSIS OF VARIANCE FOR CATEGORY RATING (UNACCEPTABILITY) OF SESSION I NOISE AS A FUNCTION OF NOISE SENSITIVITY AND LISTENING POSITION

Source	SS	df	MS	F
Rows (noise sensitivity)	0.675	1	0.675	2.189
Columns (listening position)	1.542	5	0.3084	1.0003
Interaction	3.075	5	0.615	1.9948
Error (within cells)	33.300	108	0.3083	———
Totals	38.592	119	———	———

TABLE A-I.—ATTENUATION OF TRAILERS

Trailer position	A	B	C
Attenuation (PNdB)	11.0	.13.9	11.3
Mean attenuation	12.0		

TABLE A-II.—SPECIFICATIONS OF RECORDING SYSTEM

Magnetic recording system	Specification
Sangamo 350	Maximum frequency for full dynamic range—20 kHz Dynamic range 40 dB
Preamplifier, dynamic 7509/PD	Frequency response dc to 100 kHz within ±0.5 dB Gain within ±0.1% of nominal Range 0 to 60 dB in 10-dB increments
Microphones	Frequency response established within ±0.5 dB from 20 Hz to 15 kHz and incorporated into analysis

TABLE A-III.—MEAN ABSORPTION BY JUDGES

Frequency, Hz	Absorption, dB
63	0
125	0
250	0
500	-1
1000	-2
2000	-3
4000	-3
8000	-3

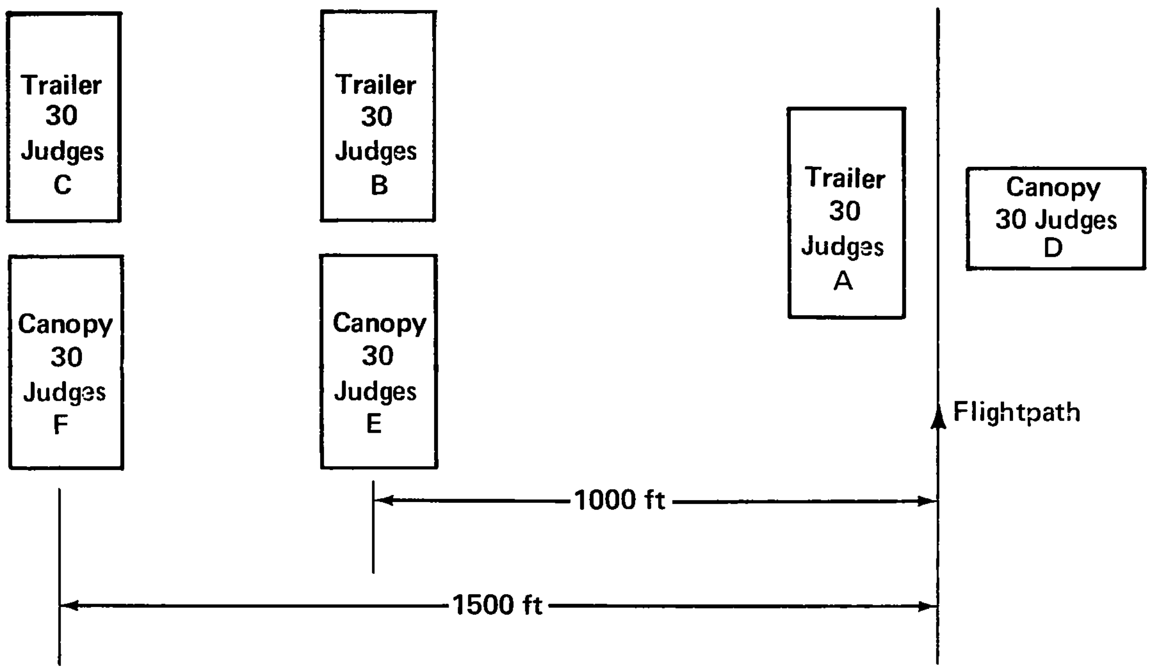


FIGURE 1.–JURY LOCATIONS 1 MILE FROM RUNWAY THRESHOLD

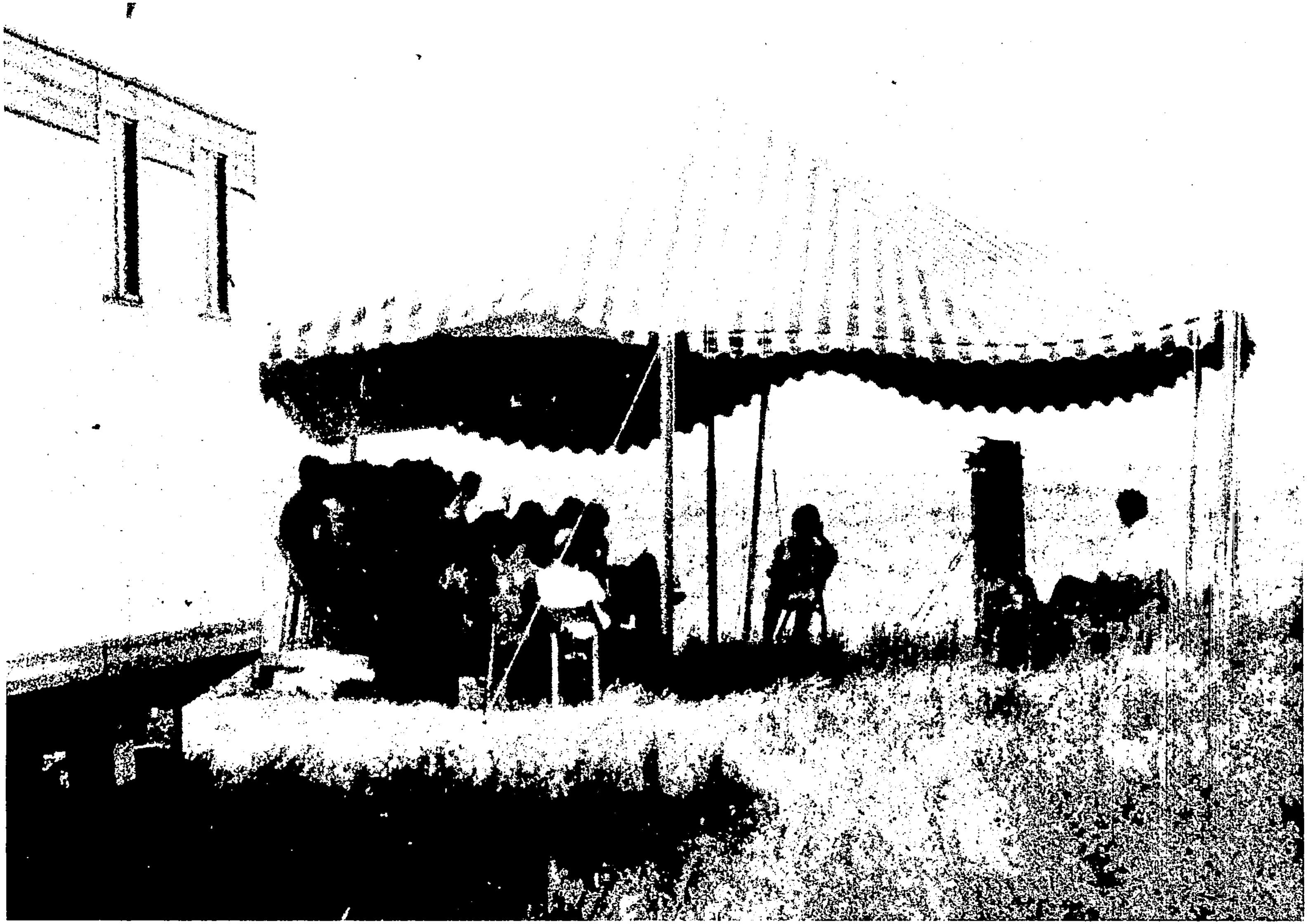


FIGURE 2.—JUDGES IN A TYPICAL LISTENING COMPLEX

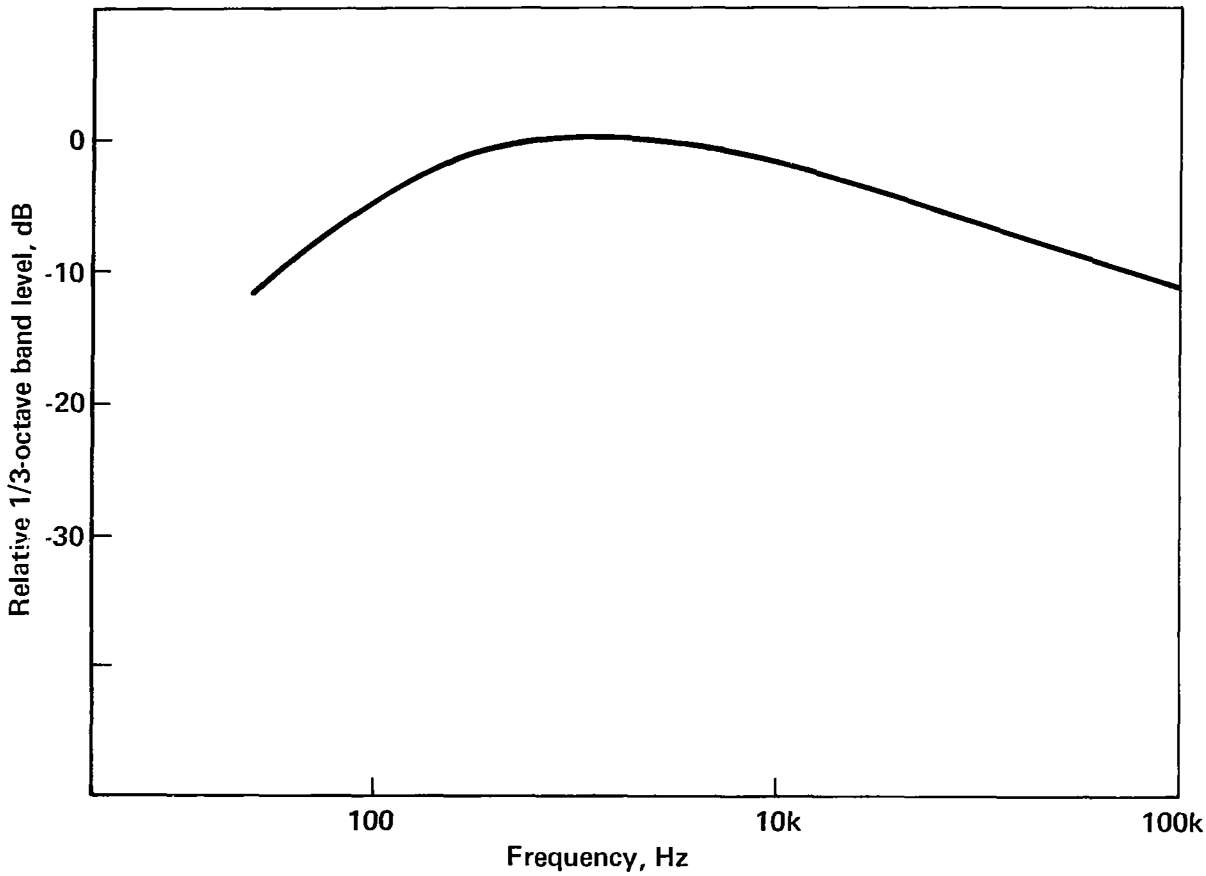


FIGURE 3.—RELATIVE 1/3-OCTAVE BAND SPECTRUM FOR USASI NOISE

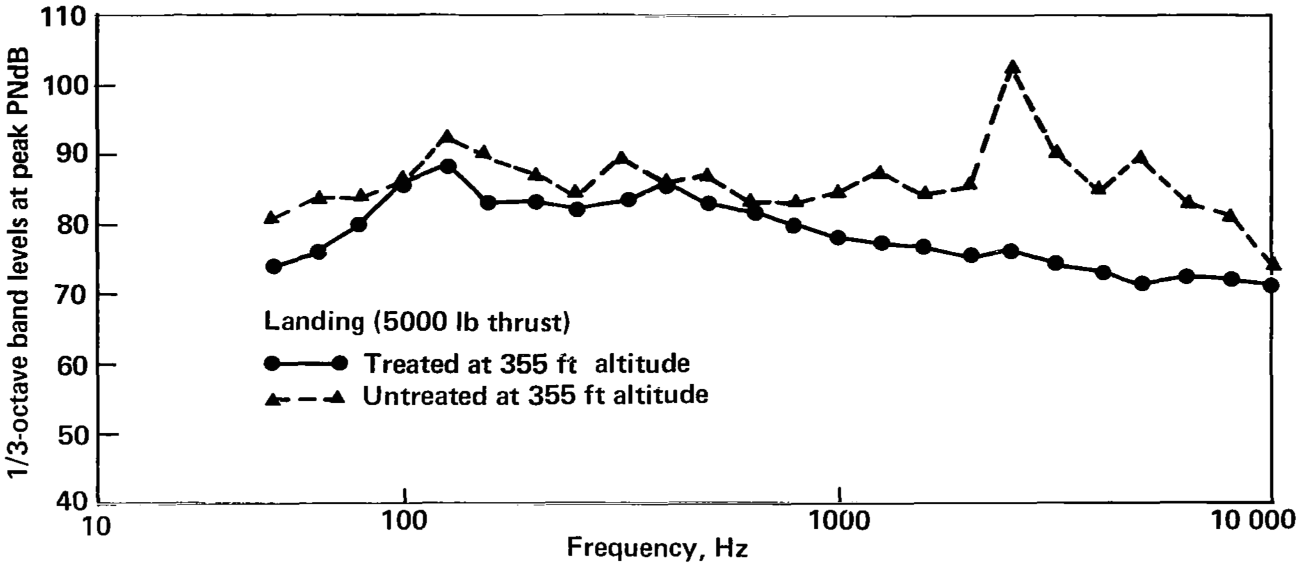


FIGURE 4.—SPECTRA FOR FLYOVERS 52 AND 53—POSITION D (SESSION I)

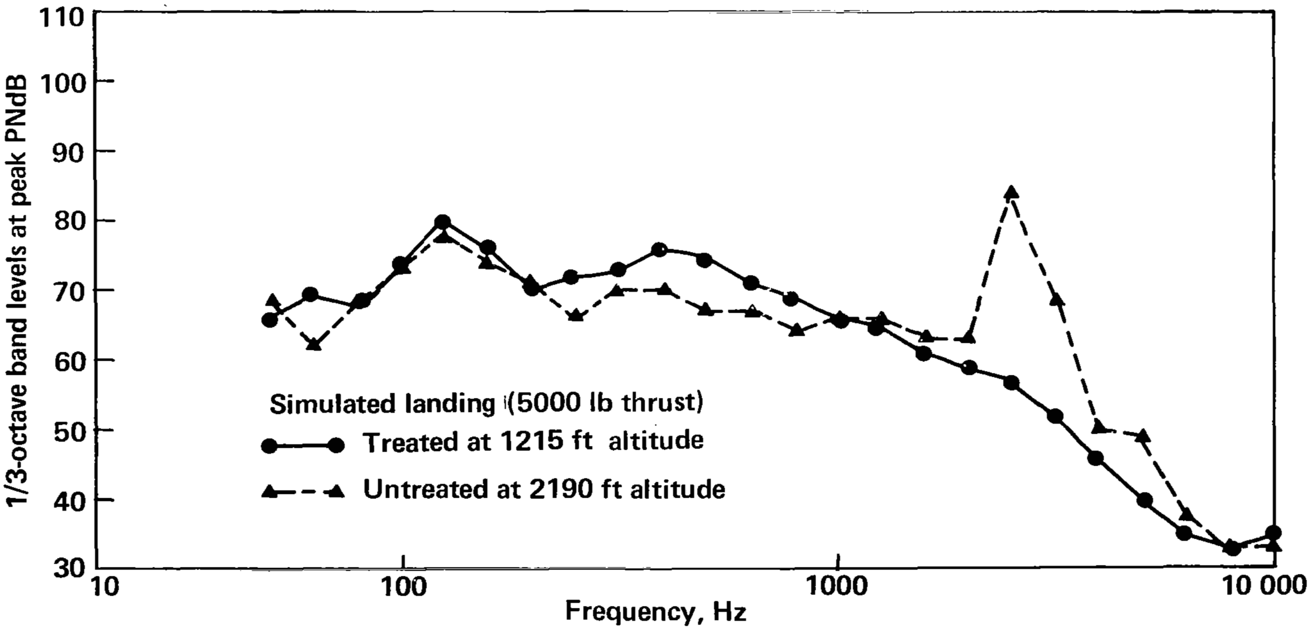


FIGURE 5.—SPECTRA FOR FLYOVERS 62 AND 63—POSITION D (SESSION I)

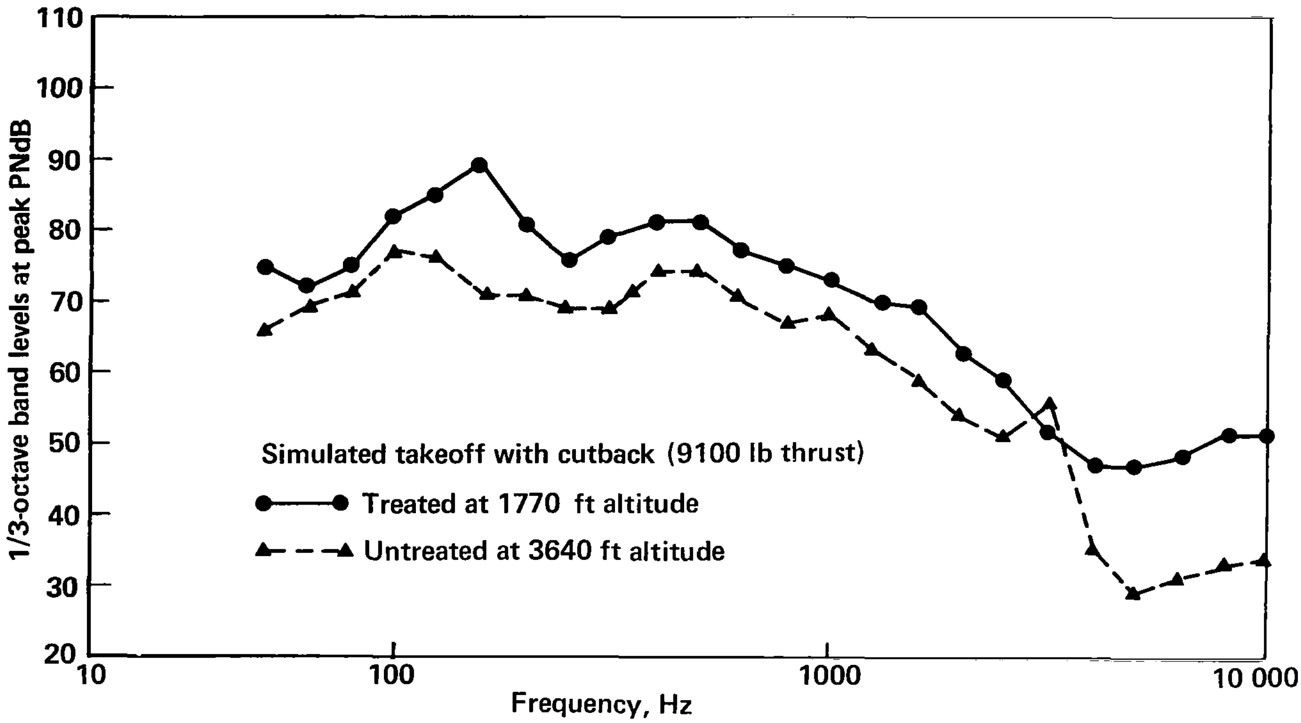


FIGURE 6.—SPECTRA FOR FLYOVERS 32 AND 33—POSITION D (SESSION II)

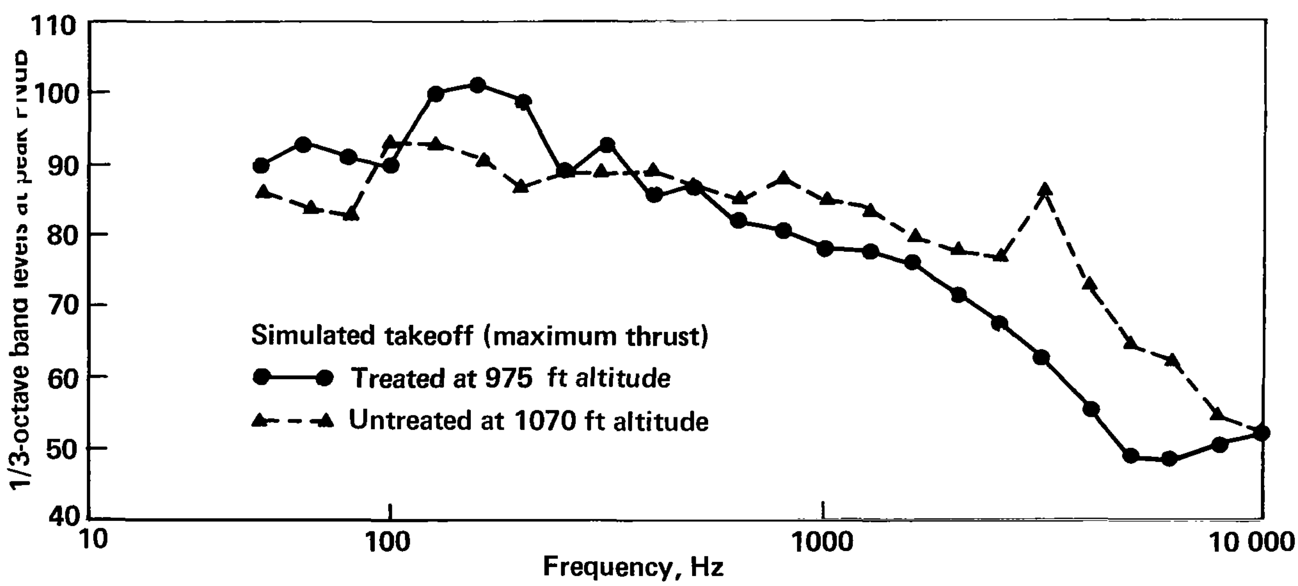


FIGURE 7.—SPECTRA FOR FLYOVERS 50 AND 51—POSITION D (SESSION I)

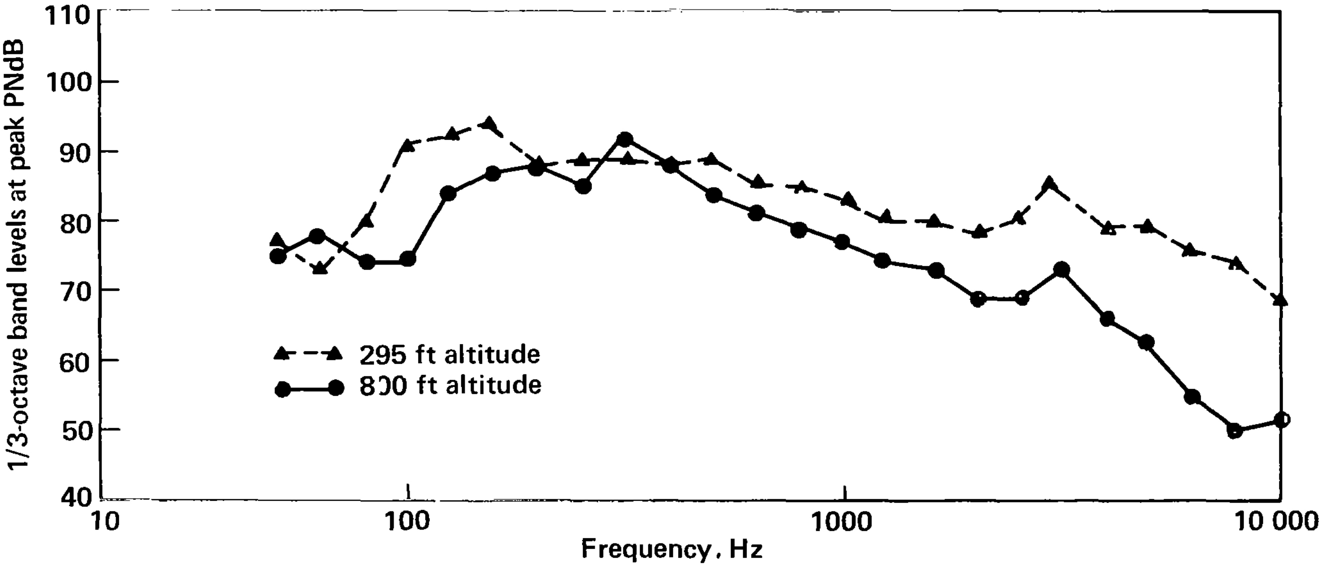
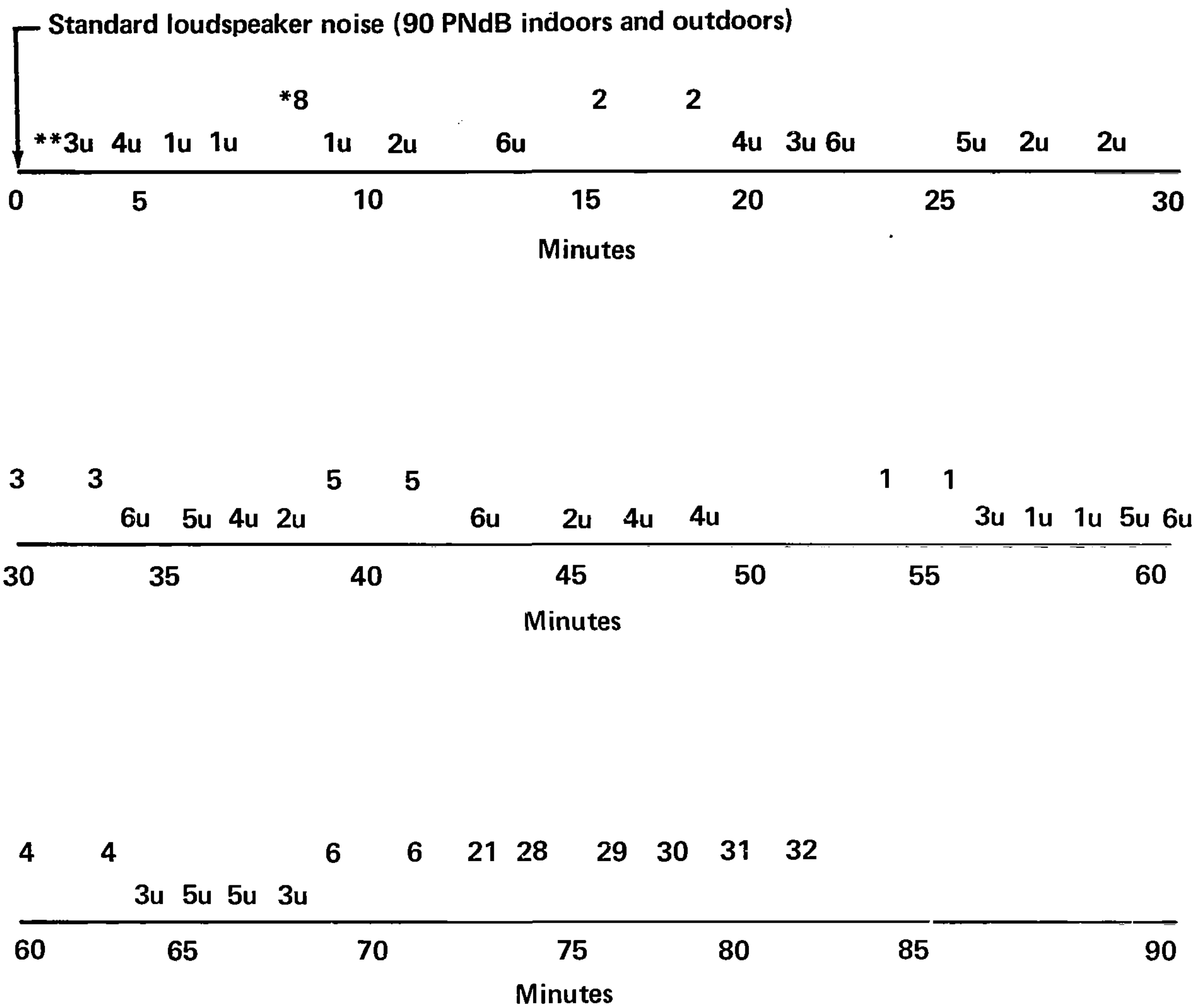


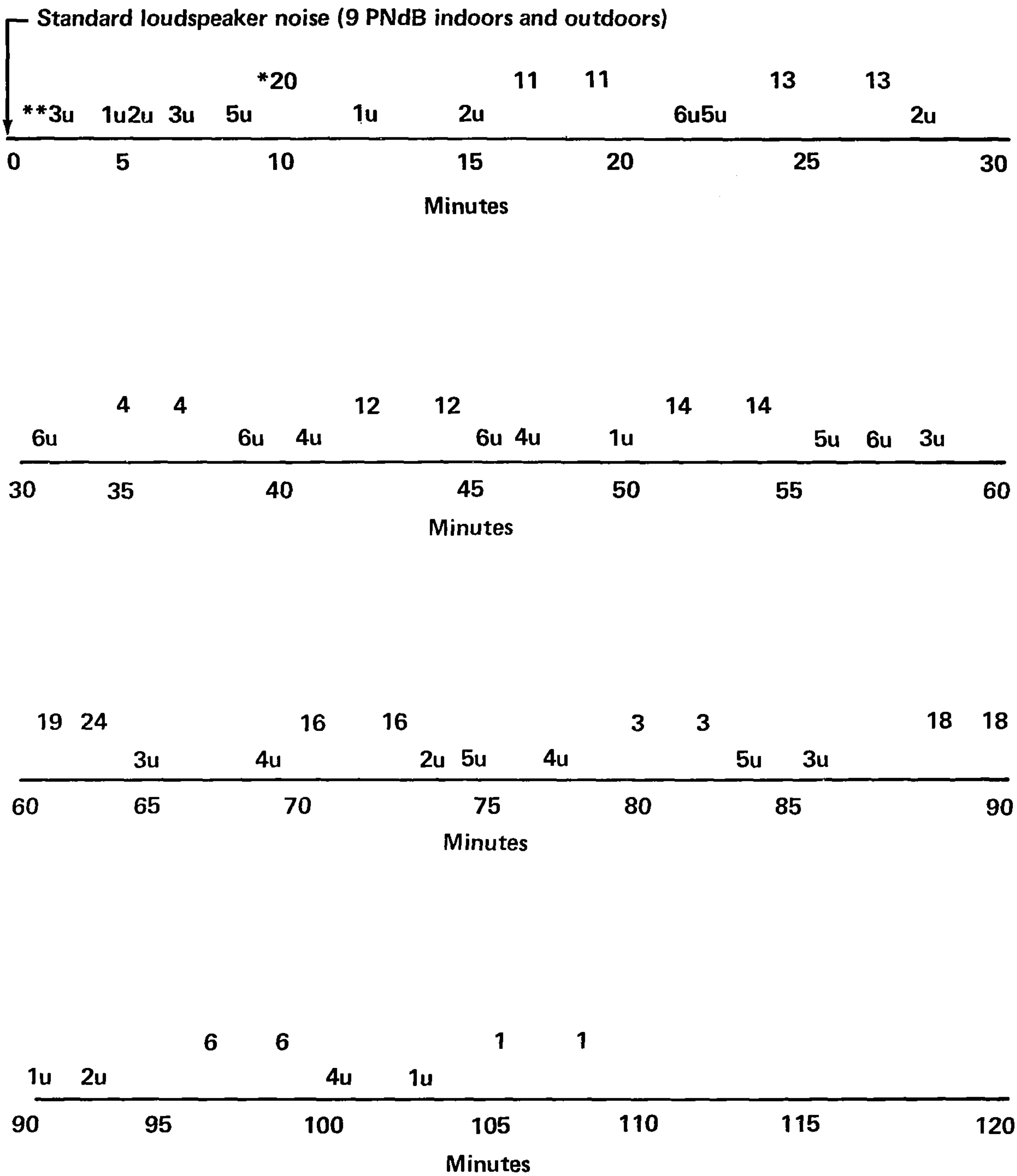
FIGURE 8.—EXAMPLES OF SPECTRA FOR BOEING 727 CASUAL FLYOVERS—POSITION D (SESSION II)



*Test flyovers (upper numbers)

**Random loudspeaker noise (lower numbers with u's); the "u" stands for USASI; the number is the sound level—1 through 6 at 5 dB apart (indoor presentation 10 dB less than outdoor presentation).

FIGURE 9.—APPROXIMATE TIME FOR 14 TEST FLYOVERS AND 30 RANDOM NOISES (SESSION I)



*Test flyovers (upper numbers)
**Random loudspeaker noise (lower numbers with u's); the "u" stands for USASI; the number is the sound level—1 through 6 at 5 dB apart (indoor presentation 10 dB less than outdoor presentation).

FIGURE 10.—APPROXIMATE TIMES FOR 23 TEST FLYOVERS AND 30 RANDOM NOISES (SESSION II)

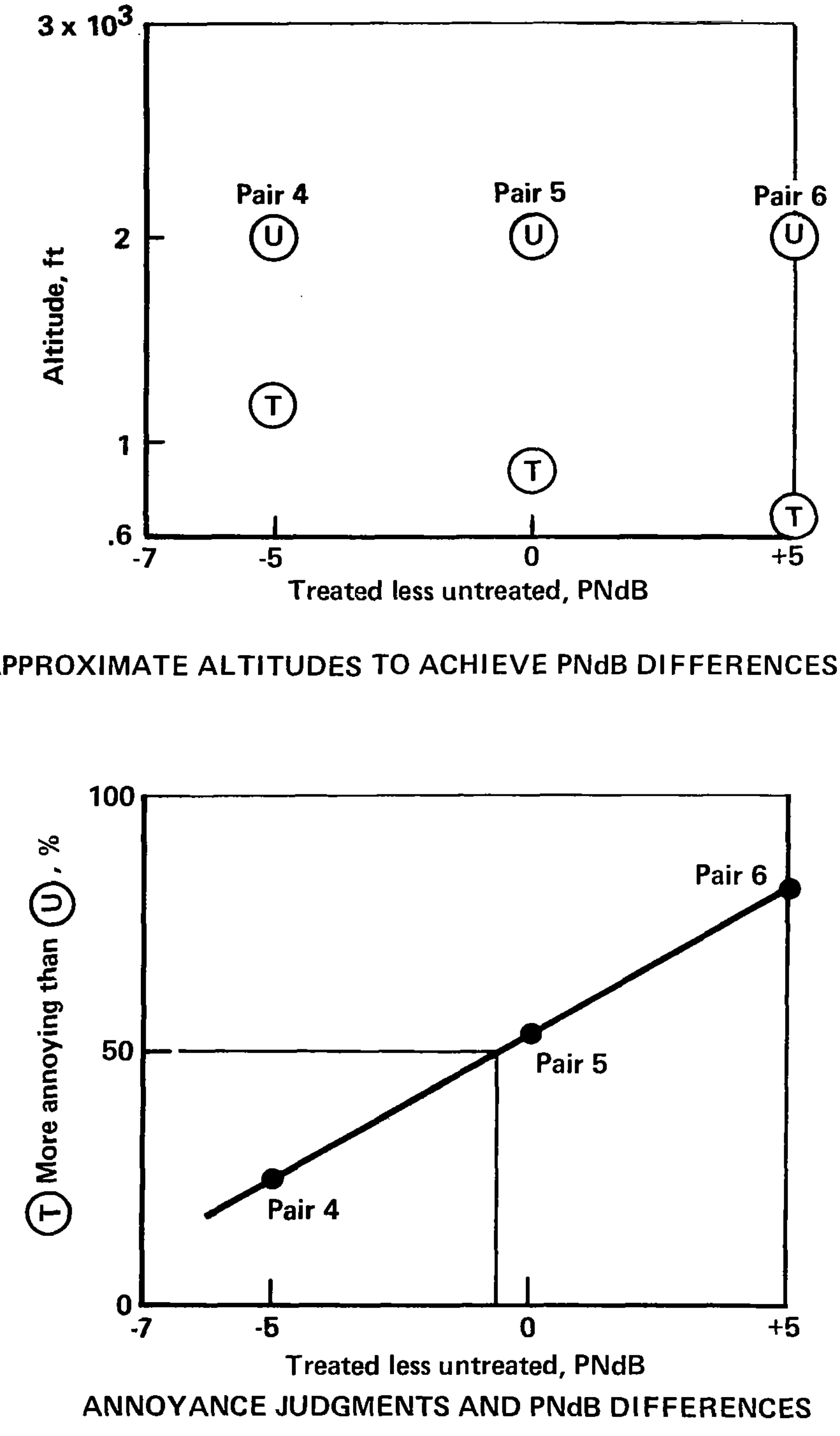


FIGURE 11.—METHOD OF OBTAINING POINT OF EQUAL ANNOYANCE FROM CONSTANT-STIMULUS-DIFFERENCES DATA

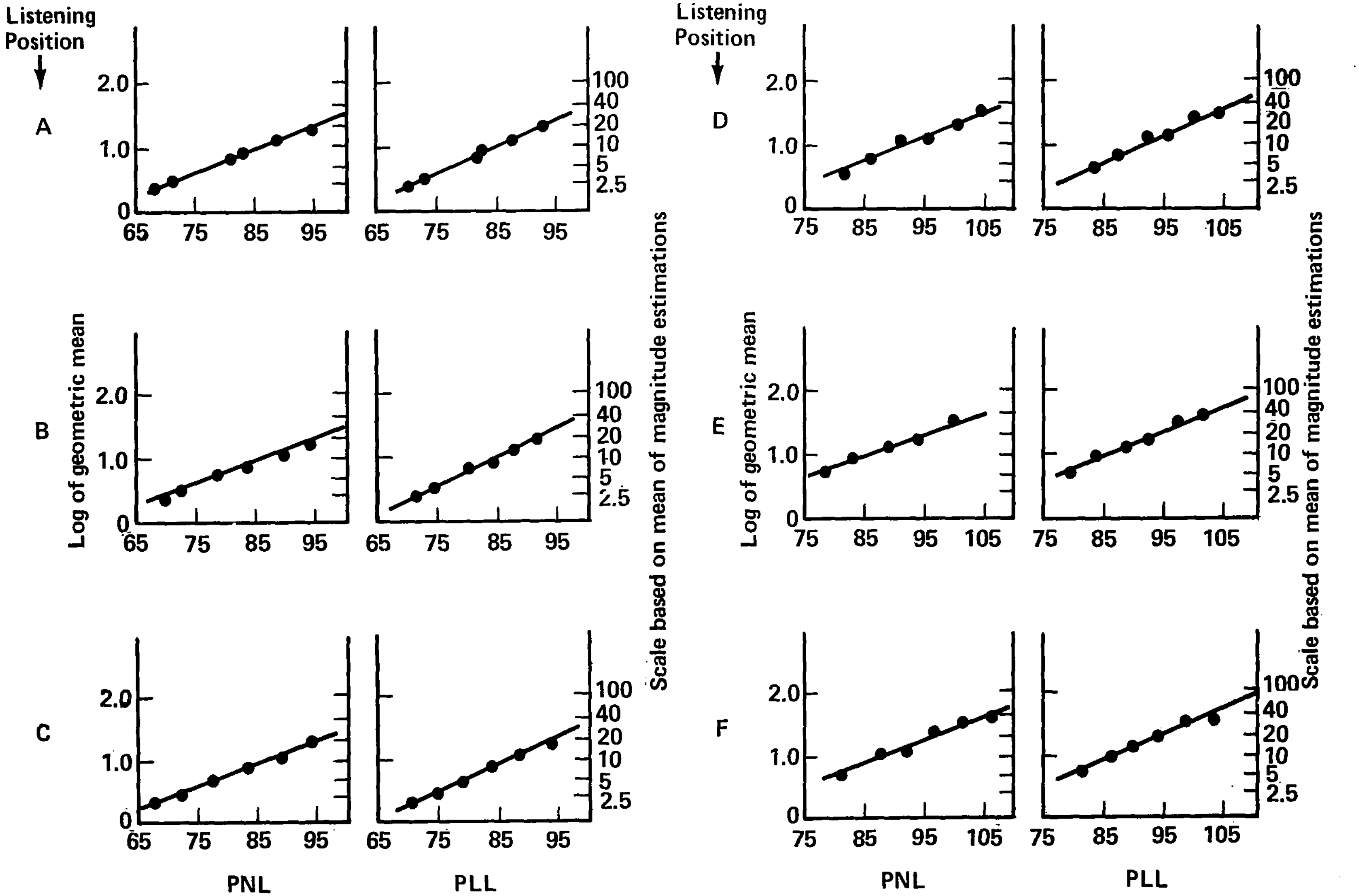


FIGURE 12.–GEOMETRIC MEANS OF MAGNITUDE ESTIMATIONS AS A FUNCTION OF PERCEIVED NOISE LEVEL OR PERCEIVED LOUDNESS LEVEL–LOUDSPEAKER NOISE (SESSION I)

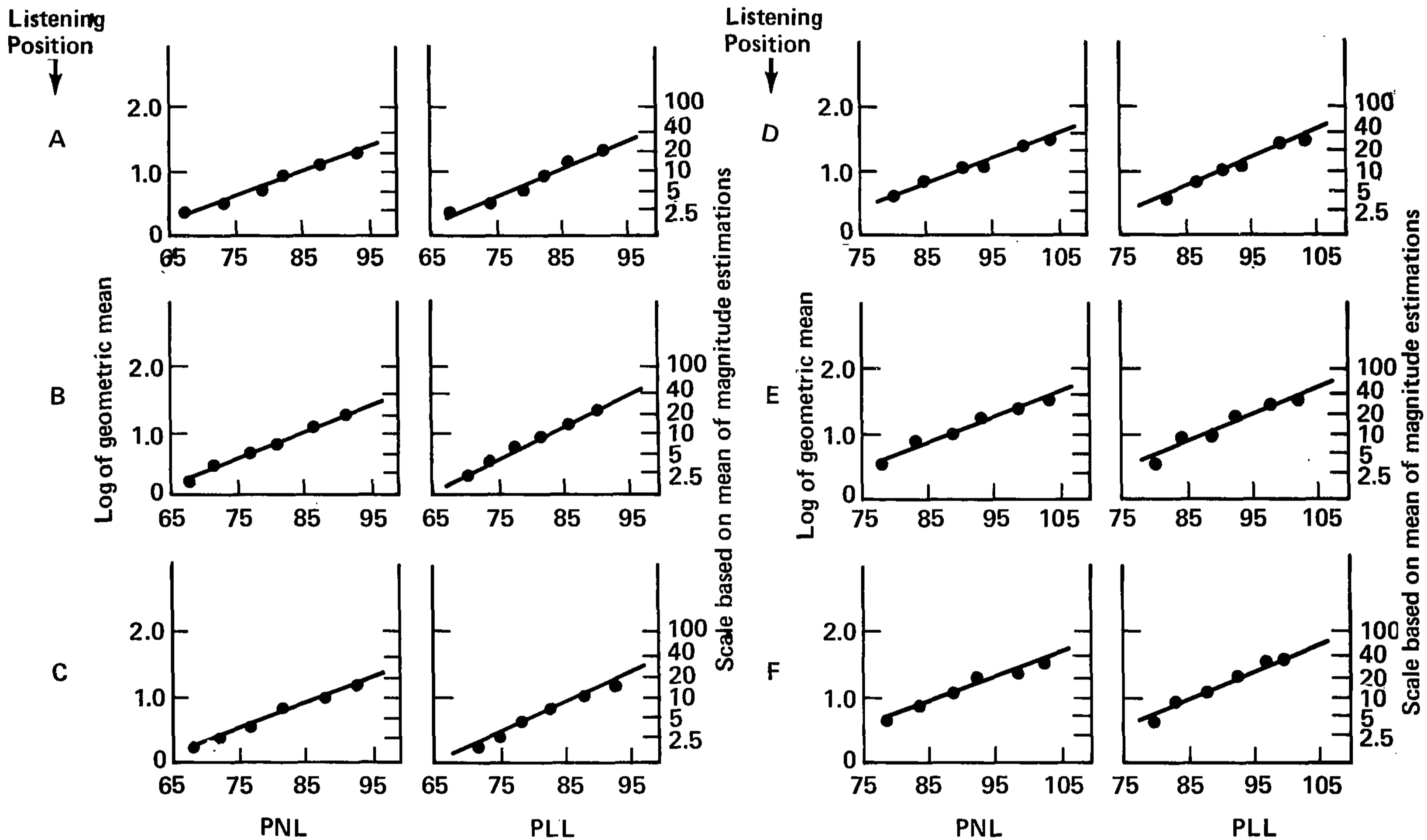


FIGURE 13.—GEOMETRIC MEANS OF MAGNITUDE ESTIMATIONS AS A FUNCTION OF PERCEIVED NOISE LEVEL OR PERCEIVED LOUDNESS LEVEL—LOUDSPEAKER NOISE (SESSION II)

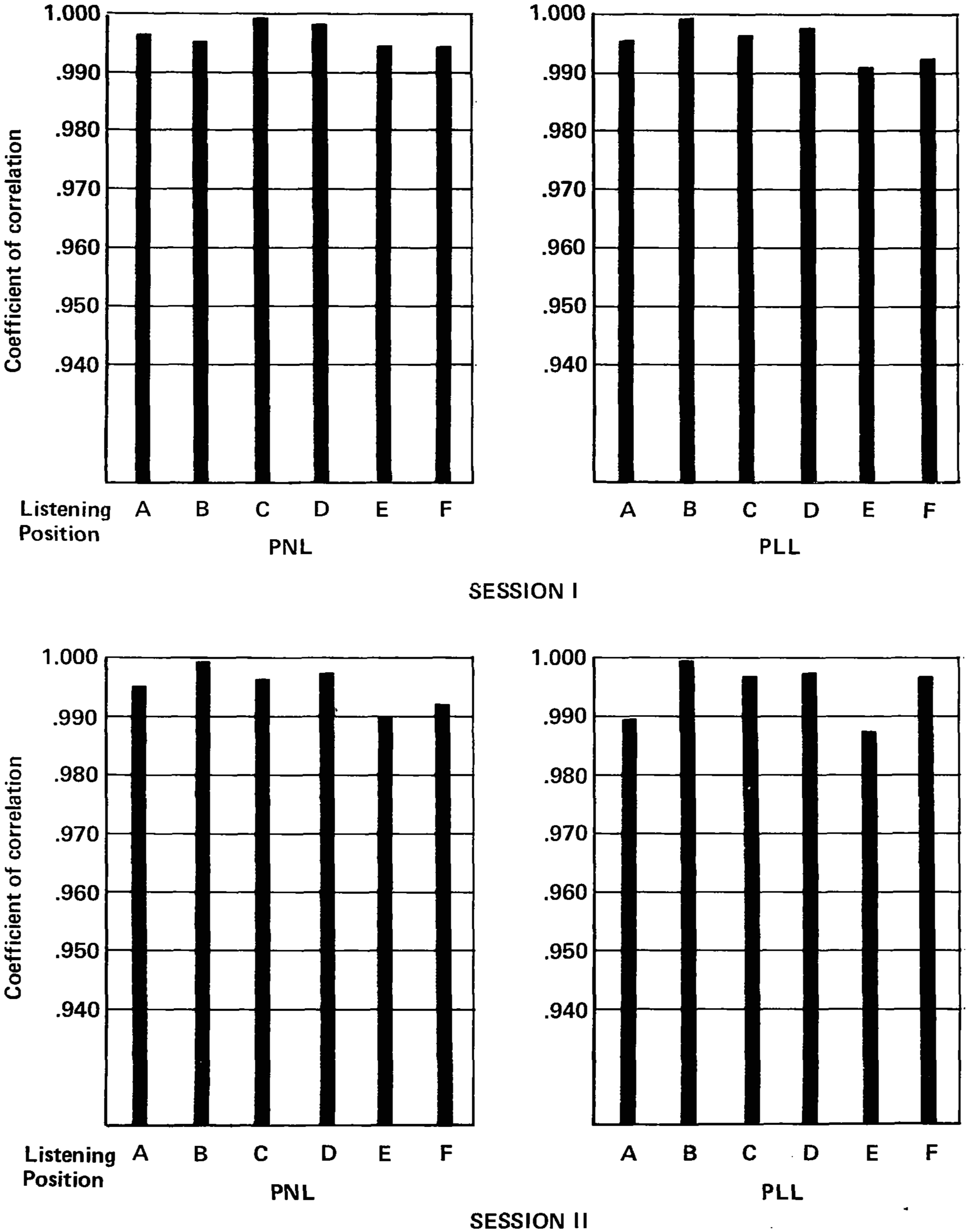


FIGURE 14. —CORRELATION COEFFICIENTS BETWEEN JUDGMENTS AND PNL OR PLL

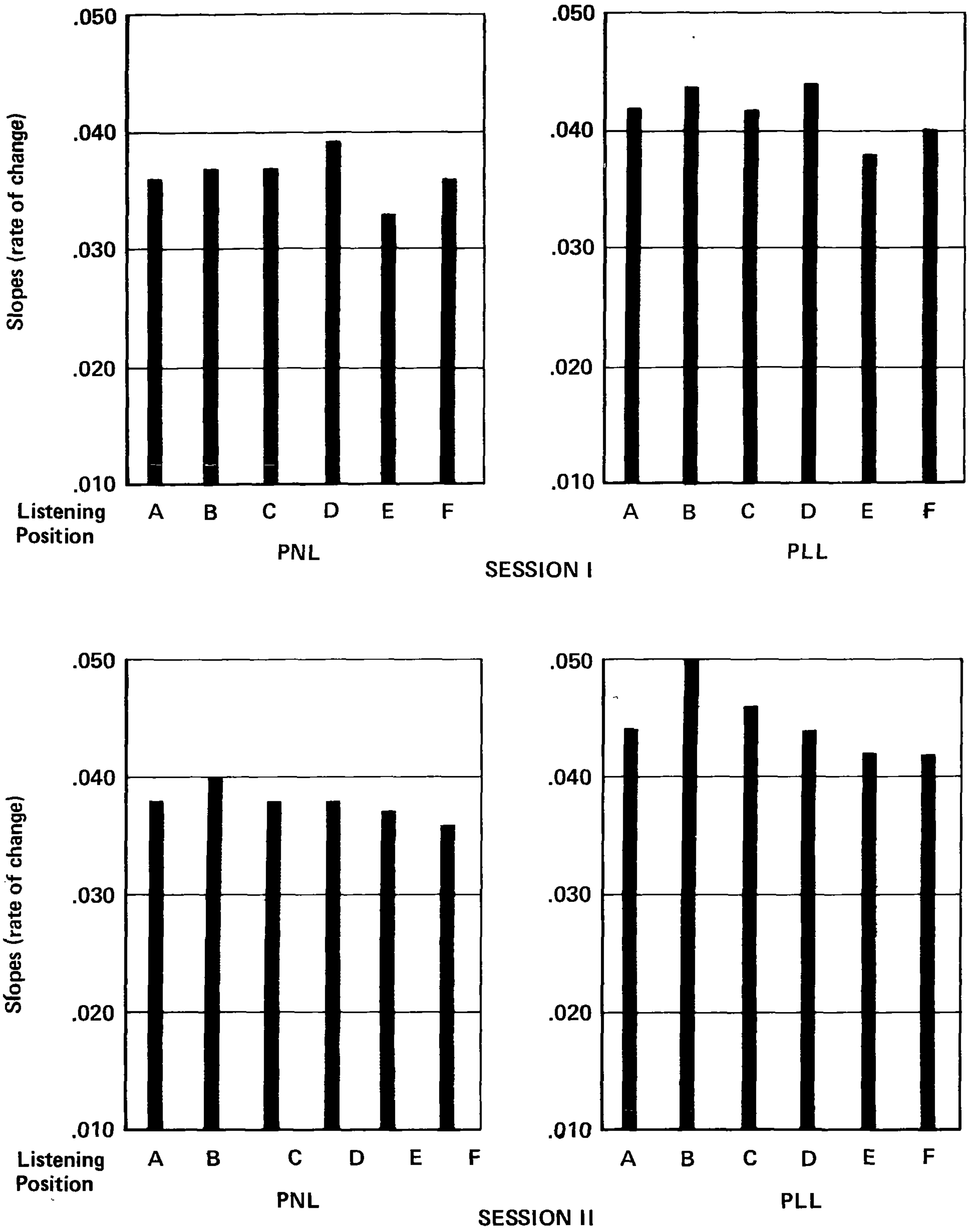


FIGURE 15.—RATES OF CHANGE OF ANNOYANCE—ARTIFICIAL NOISE

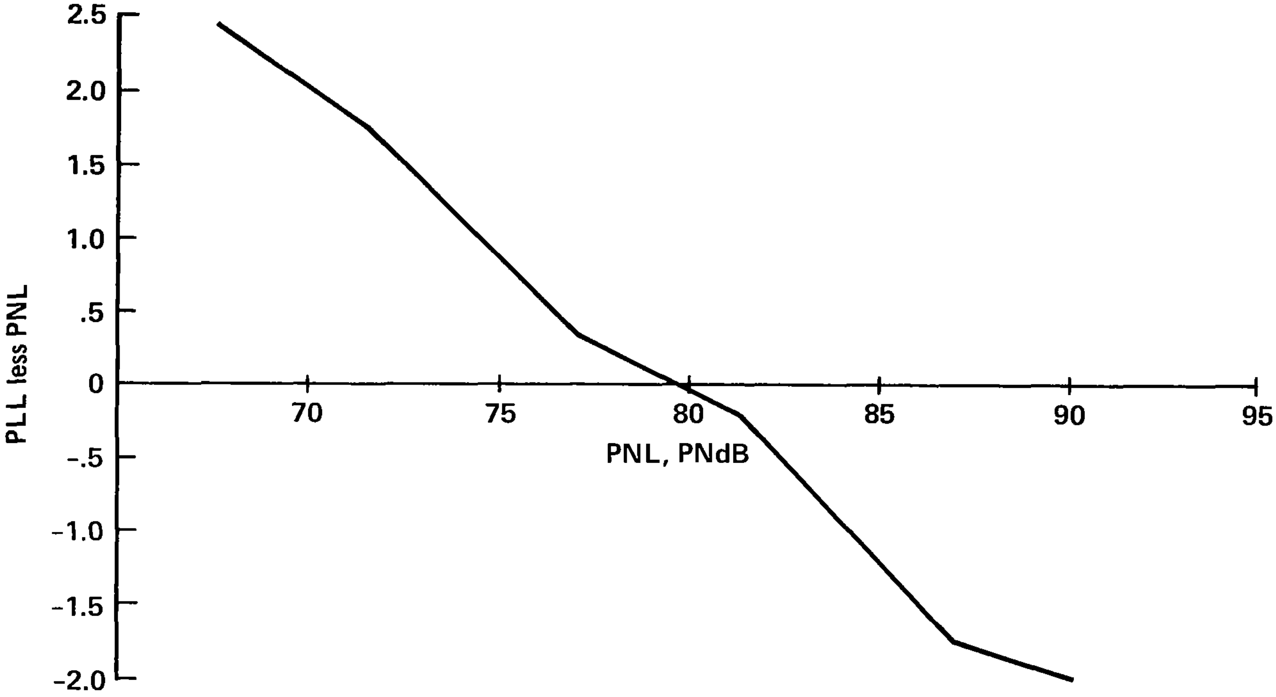


FIGURE 16.—DIFFERENCE BETWEEN PLL AND PNL AS A FUNCTION OF LEVEL OF USASI NOISE—POSITION B

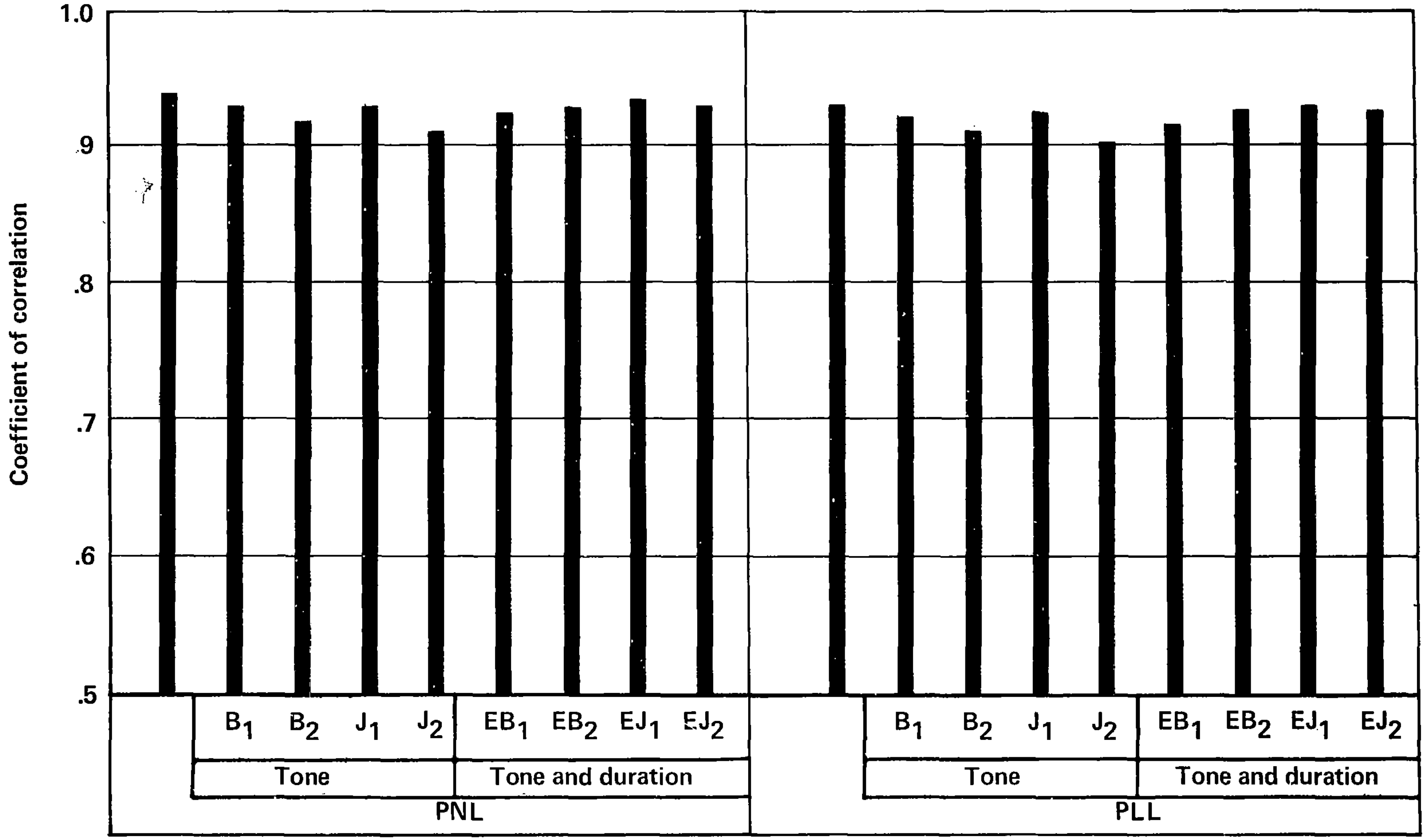


FIGURE 17.—RELATIONSHIP BETWEEN SUBJECTIVE EVALUATIONS AND ENGINEERING CALCULATION PROCEDURES—ALL AIRPLANES (SESSION I)

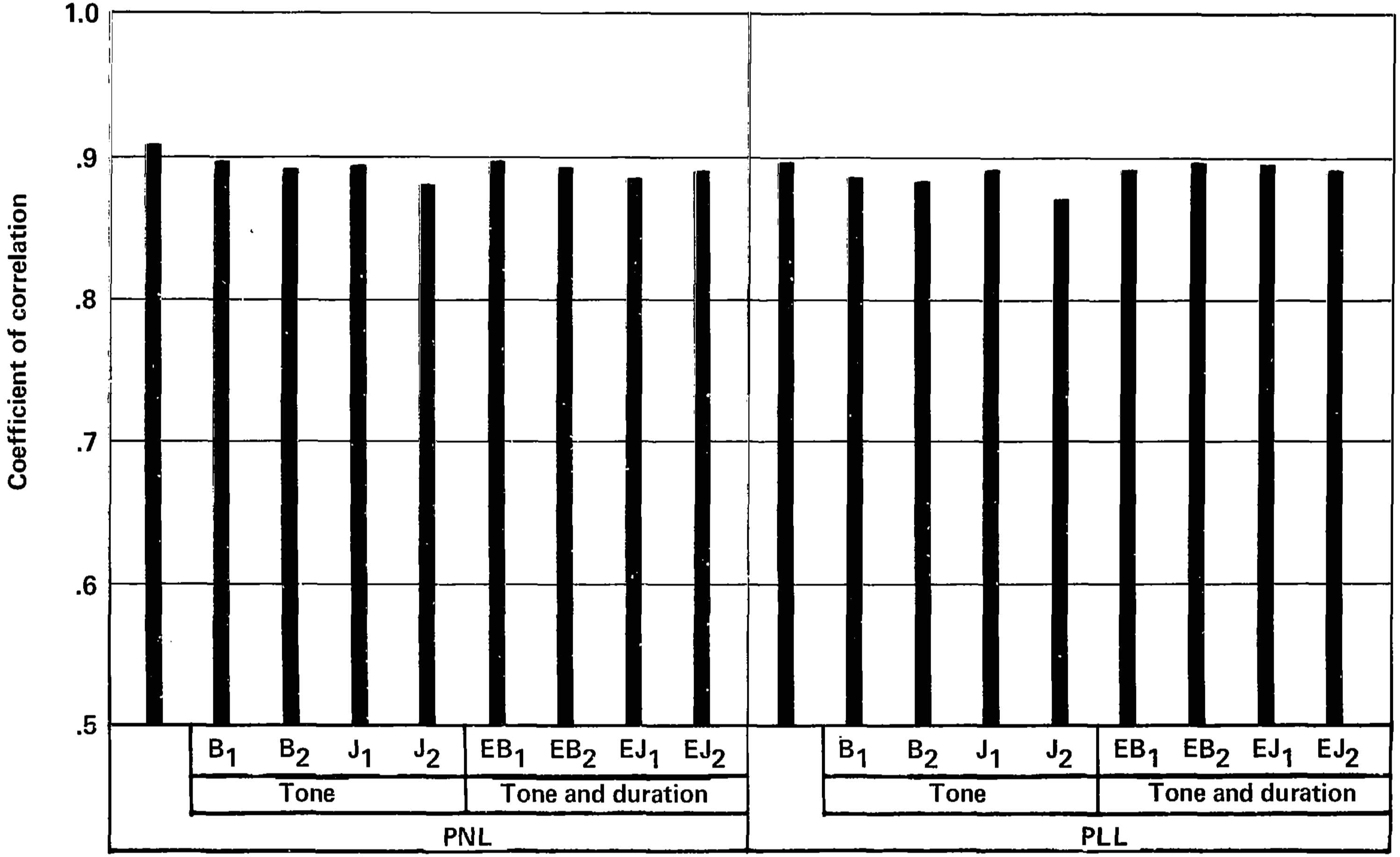


FIGURE 18.— RELATIONSHIP BETWEEN SUBJECTIVE EVALUATIONS AND ENGINEERING CALCULATION PROCEDURES— ALL AIRPLANES (SESSION II)

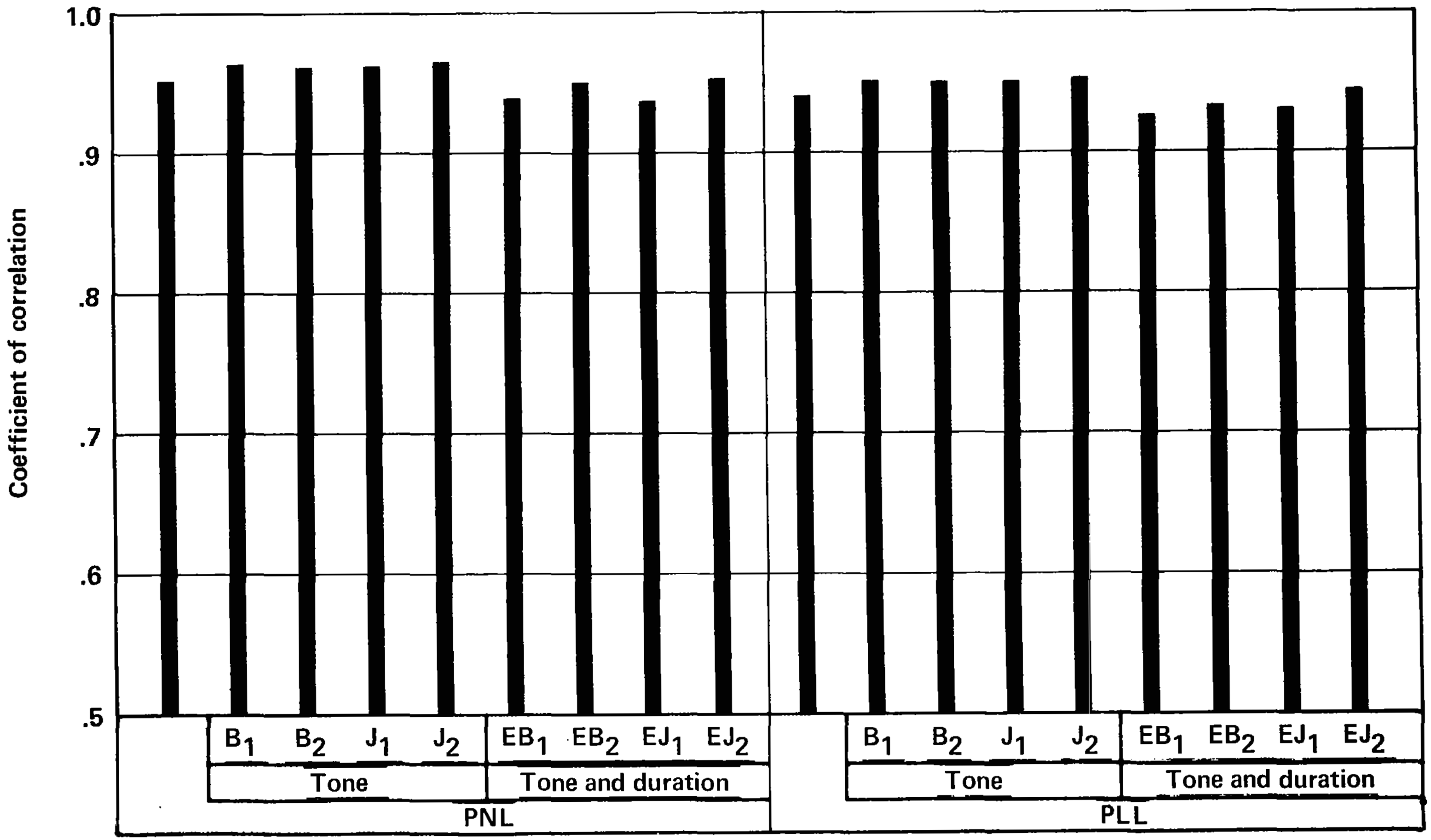


FIGURE 19.—RELATIONSHIP BETWEEN SUBJECTIVE EVALUATIONS AND ENGINEERING CALCULATION PROCEDURES— TREATED AIRPLANE (SESSION I)

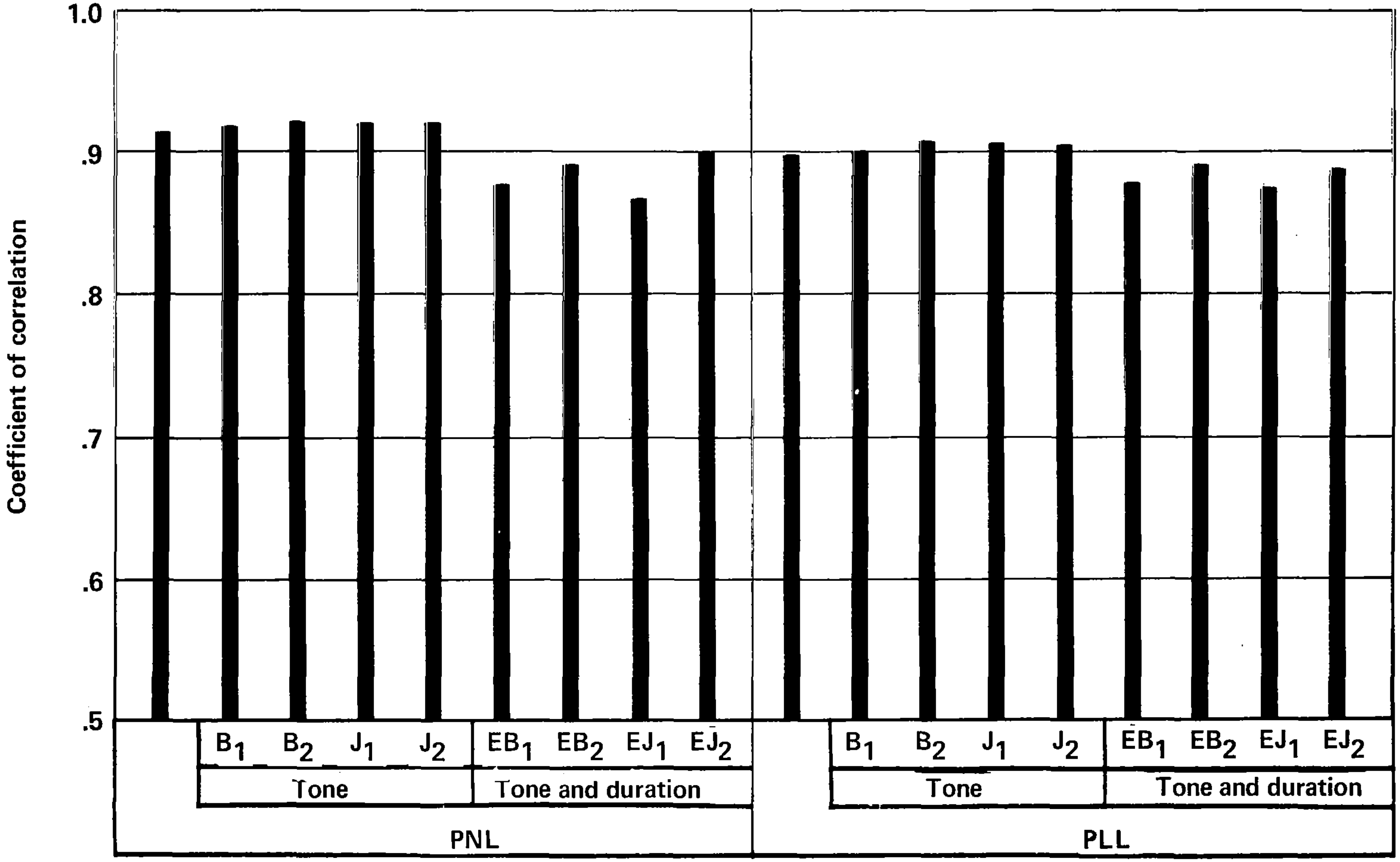


FIGURE 20.—RELATIONSHIP BETWEEN SUBJECTIVE EVALUATIONS AND ENGINEERING CALCULATION PROCEDURES—TREATED AIRPLANE (SESSION II)

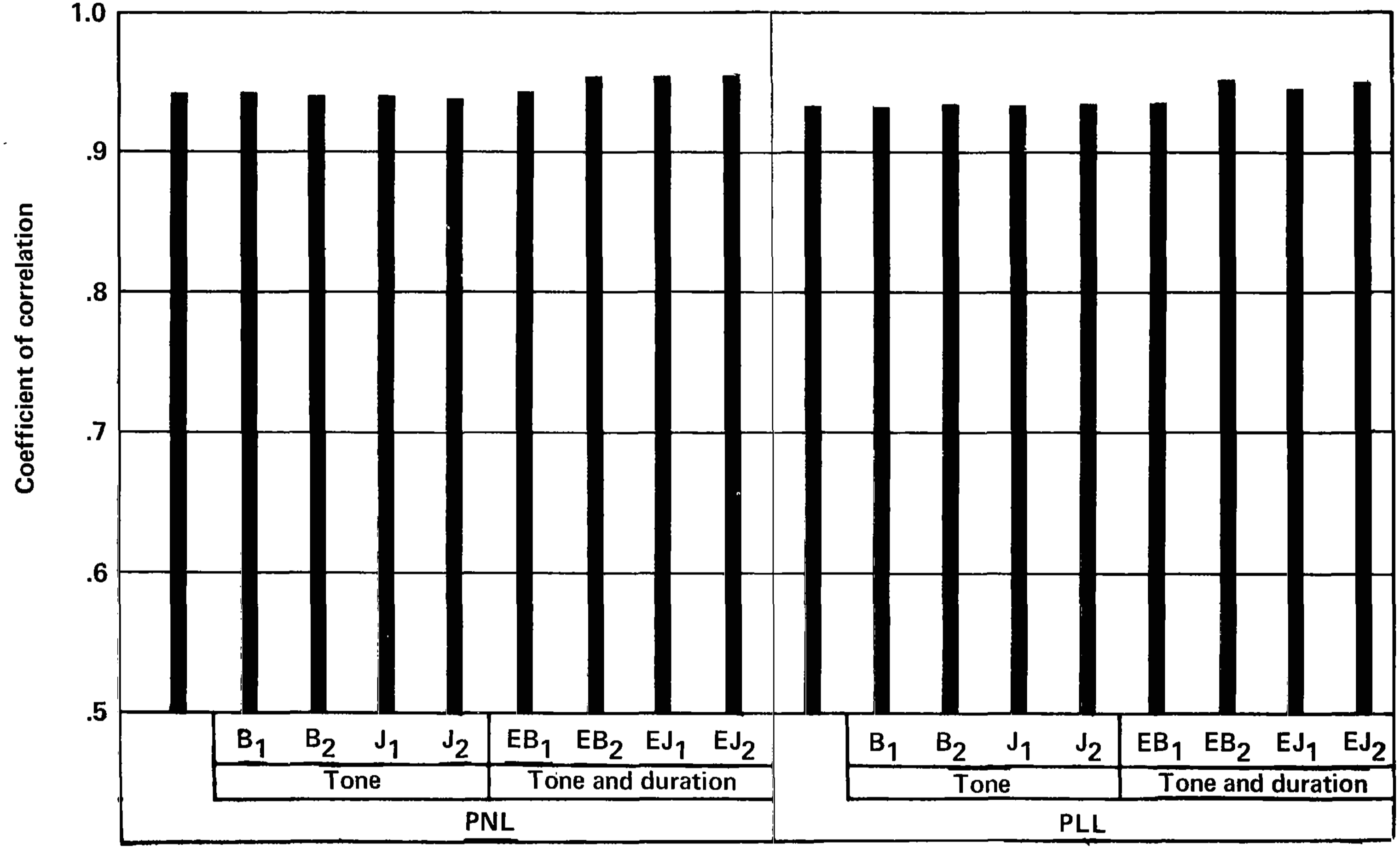


FIGURE 21.— RELATIONSHIP BETWEEN SUBJECTIVE EVALUATIONS AND ENGINEERING CALCULATION PROCEDURES — UNTREATED AIRPLANE (SESSION I)

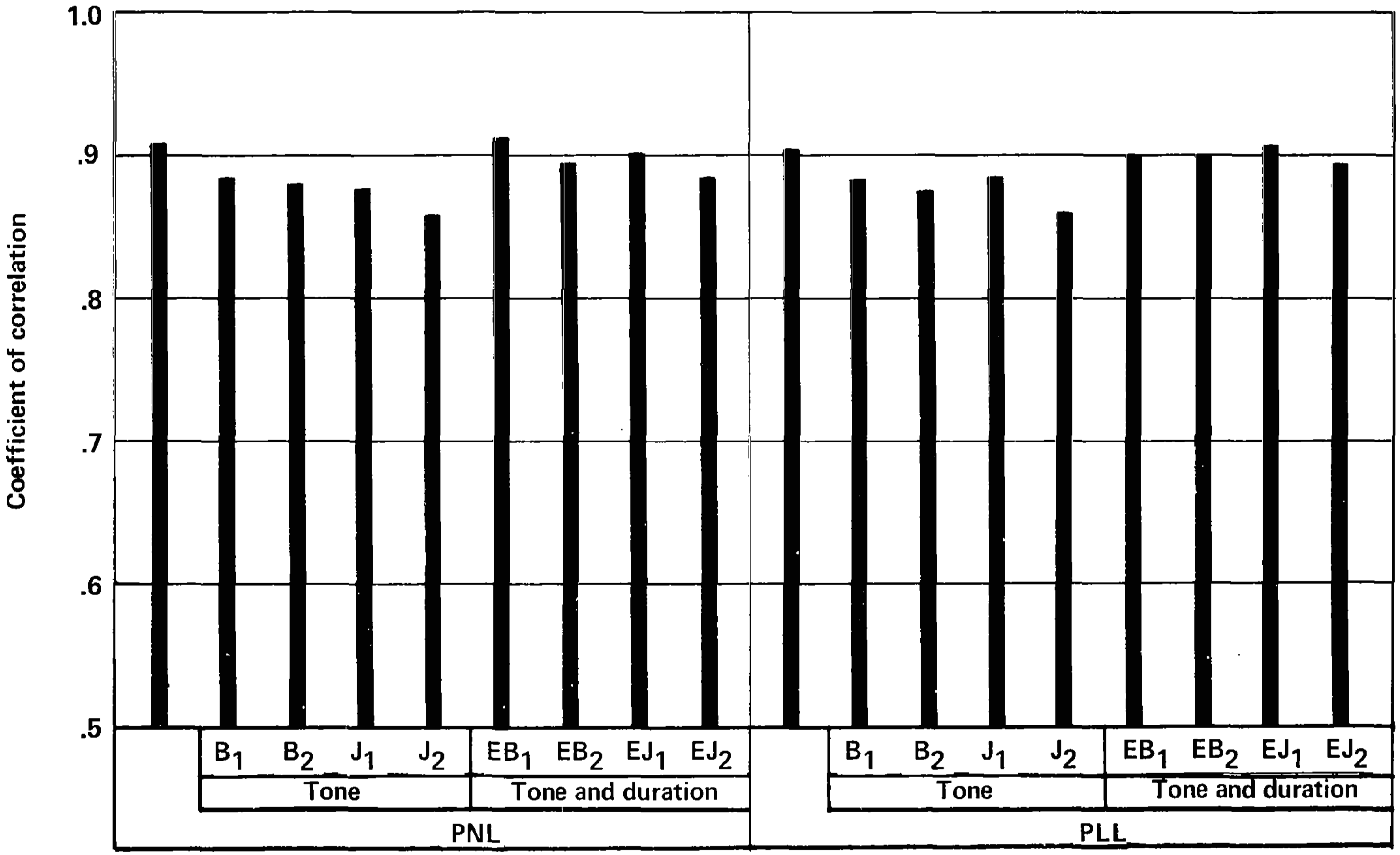


FIGURE 22.—RELATIONSHIP BETWEEN SUBJECTIVE EVALUATIONS AND ENGINEERING CALCULATION PROCEDURES—UNTREATED AIRPLANE (SESSION II)

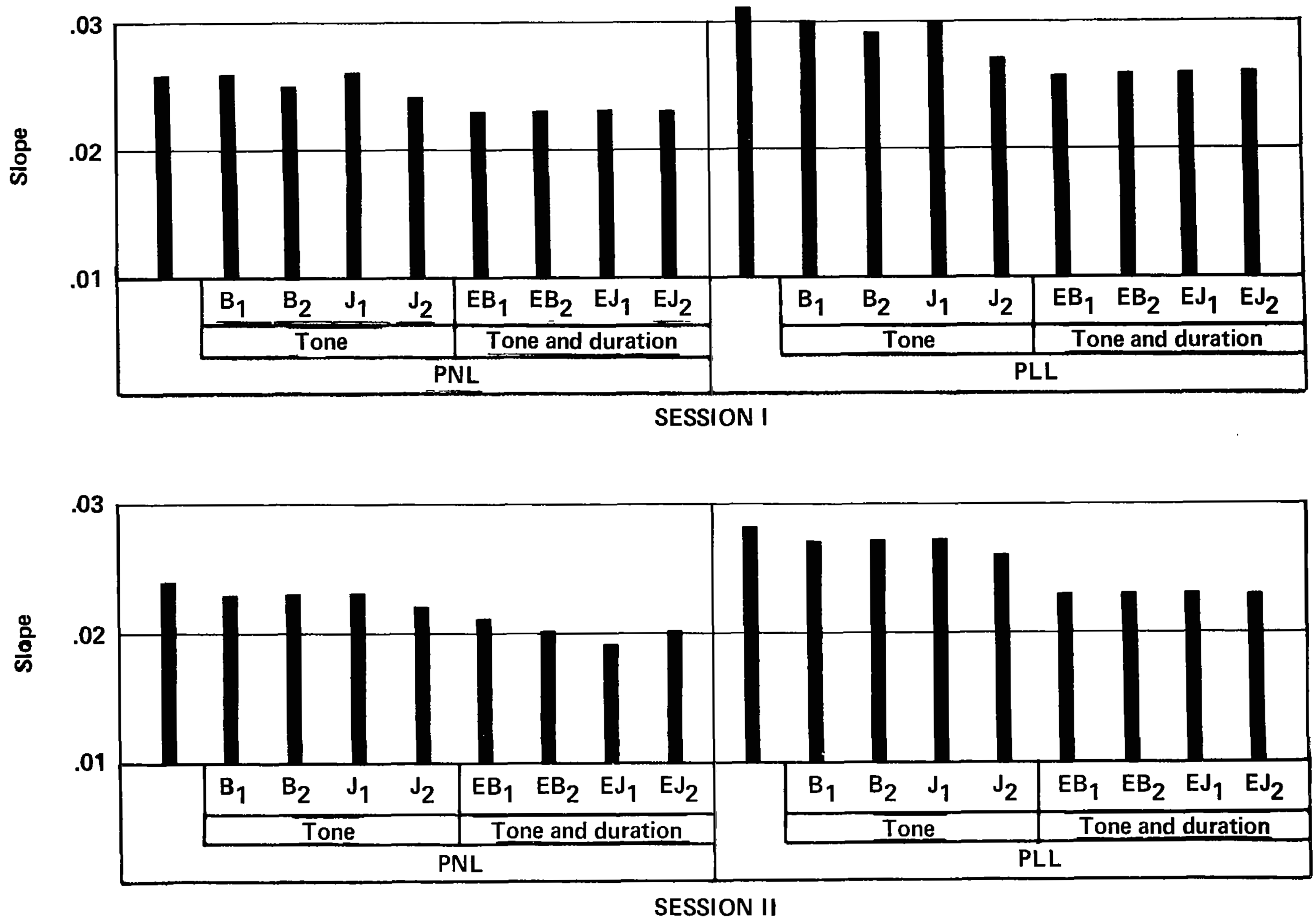


FIGURE 23.—RATES OF CHANGE OF ANNOYANCE—ALL AIRPLANES

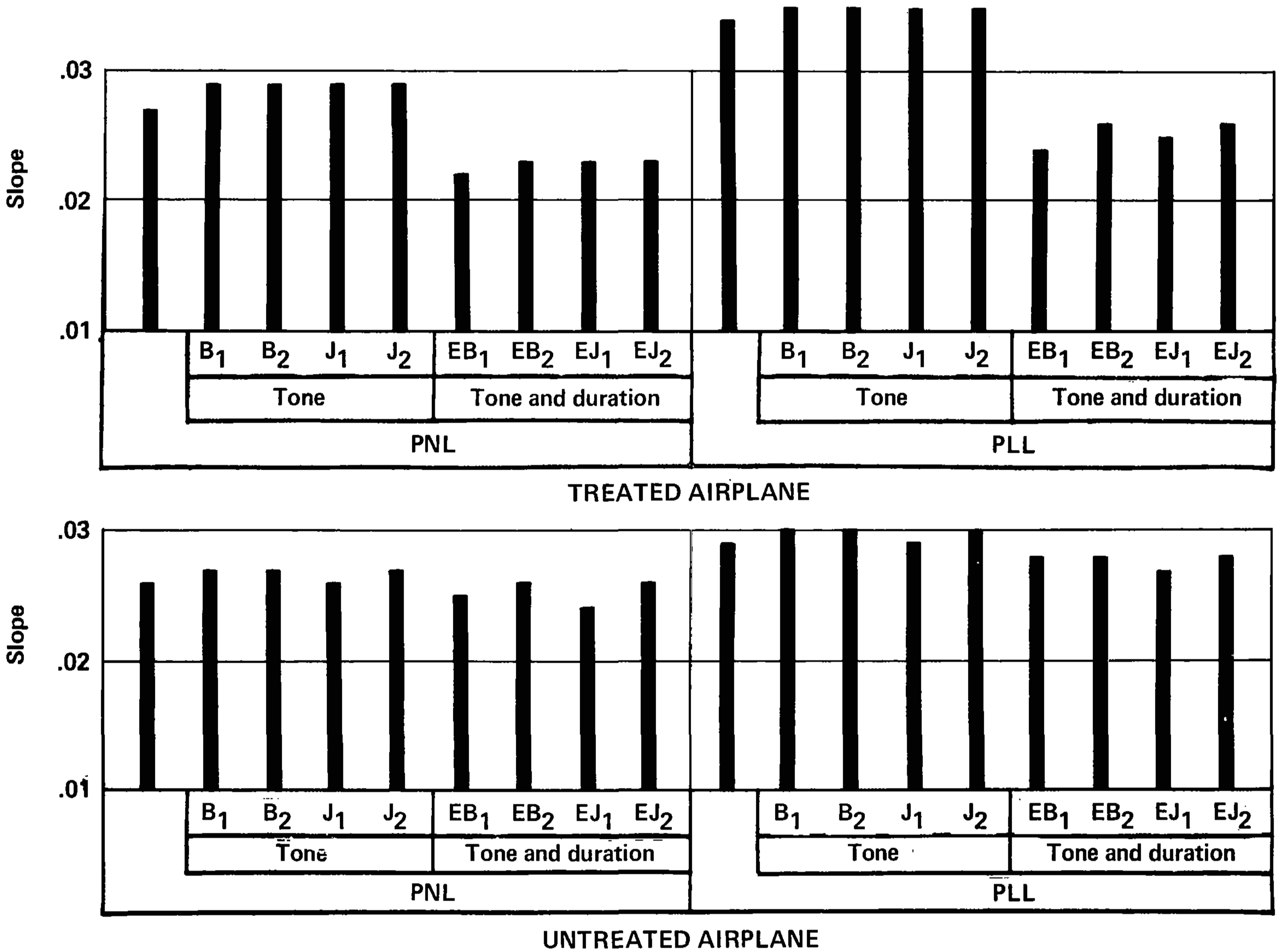


FIGURE 24.—RATES OF CHANGE OF ANNOYANCE (SESSION I)

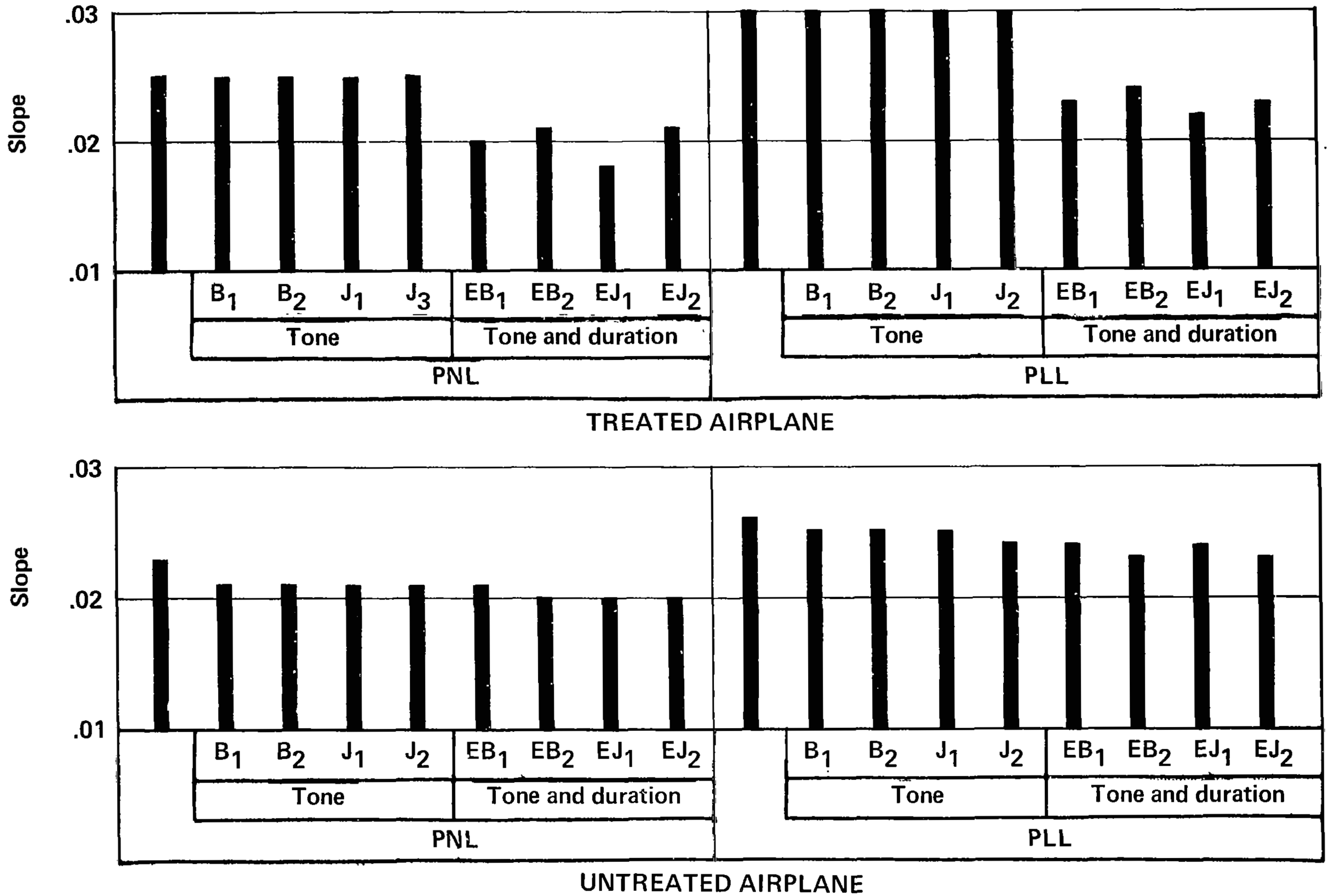


FIGURE 25.—RATE OF CHANGE OF ANNOYANCE (SESSION II)

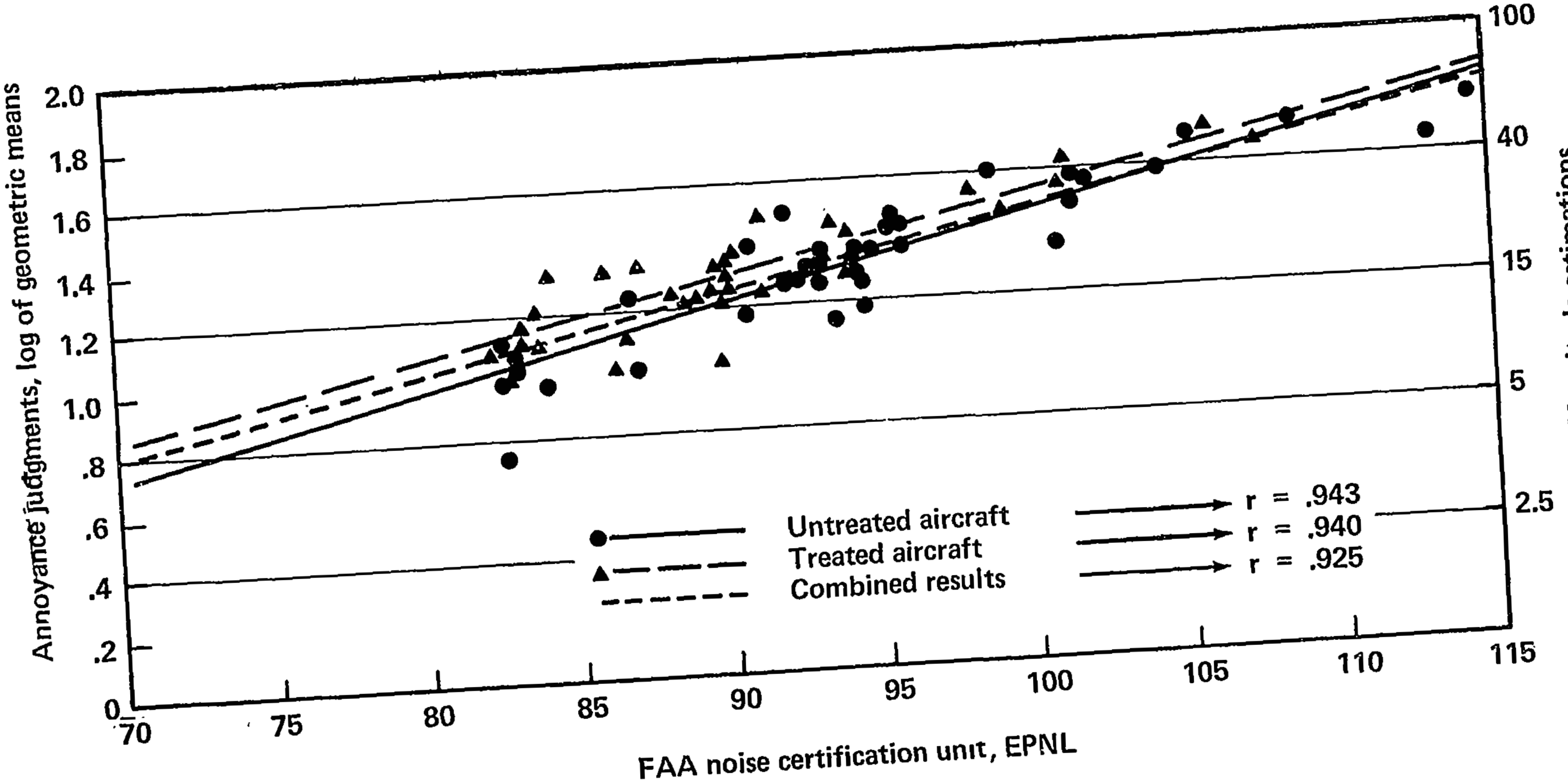


FIGURE 26.—ANNOYANCE JUDGMENT OF AIRPLANE FLYOVER NOISE AS A FUNCTION OF EFFECTIVE PERCEIVED NOISE LEVEL (EPNL) MEASUREMENT APPROACH (SESSION I)

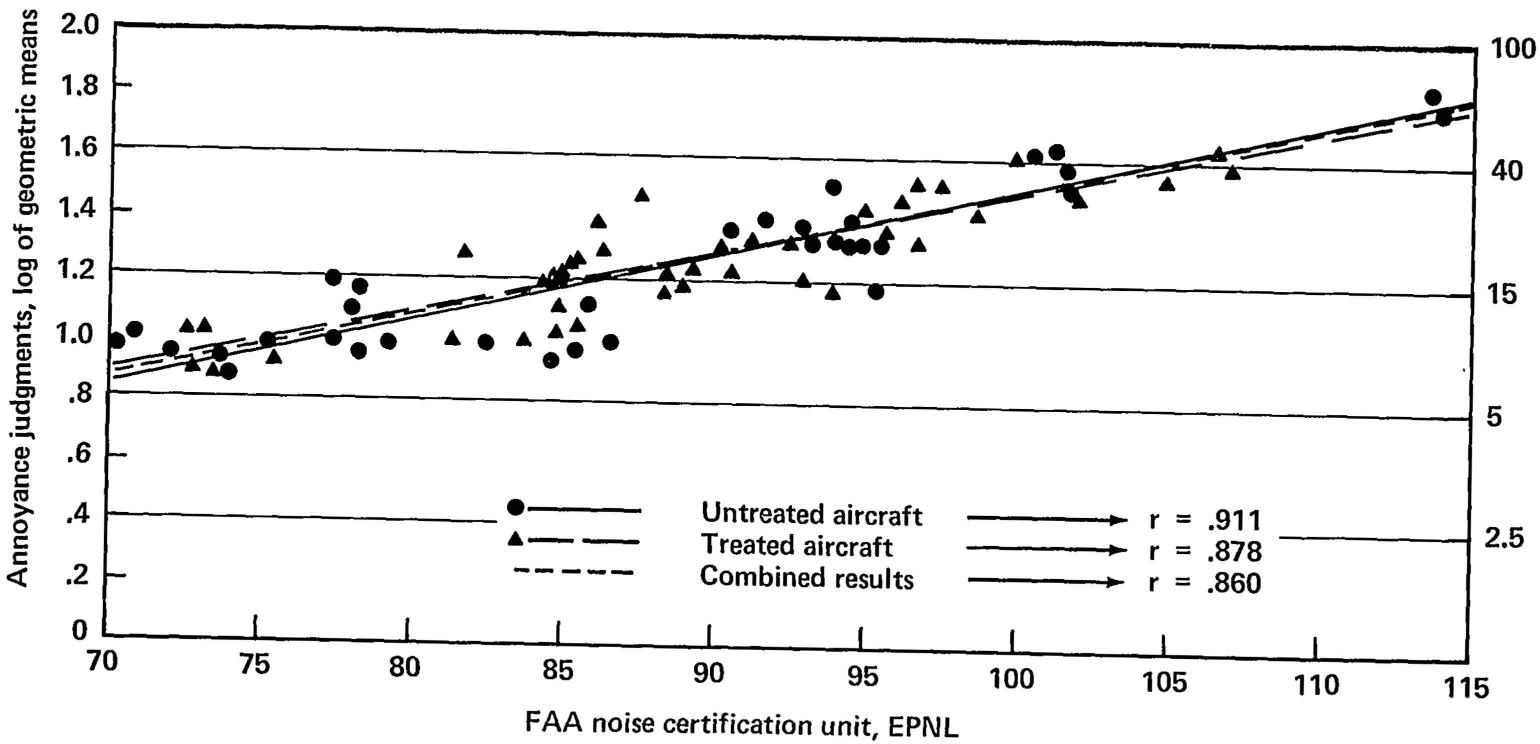


FIGURE 27.– ANNOYANCE JUDGMENTS OF AIRPLANE FLYOVER NOISE AS A FUNCTION OF EFFECTIVE PERCEIVED NOISE LEVEL (EPNL) MEASUREMENT APPROACH (SESSION II)

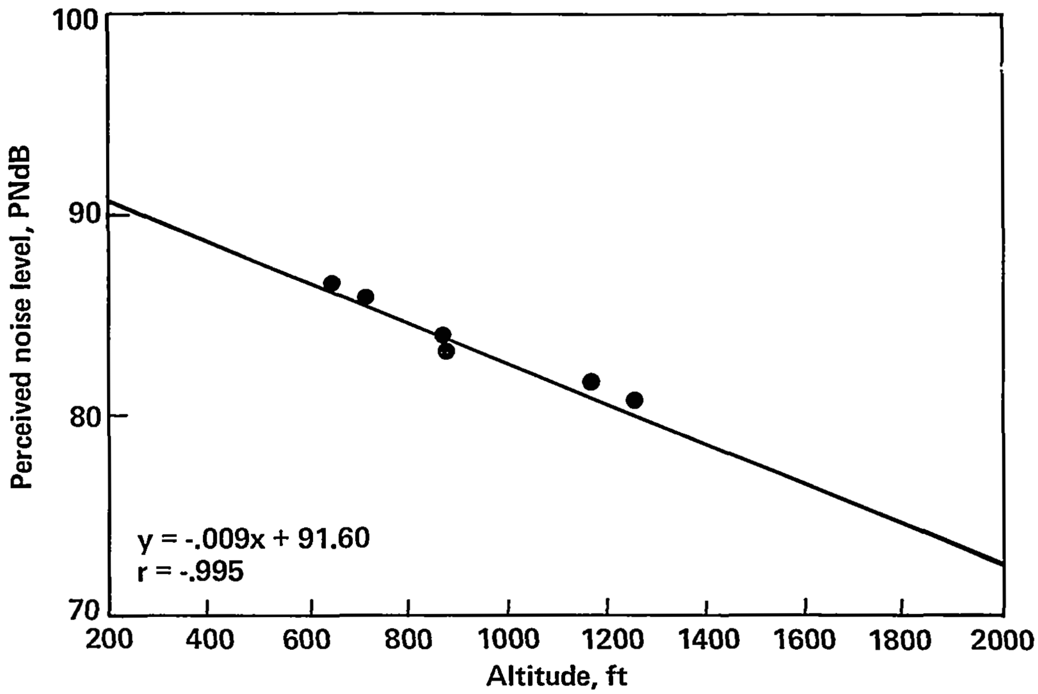


FIGURE 28.—RELATIONSHIP BETWEEN PNL AND TREATED AIRPLANE ALTITUDE—POSITION A (SESSION I)

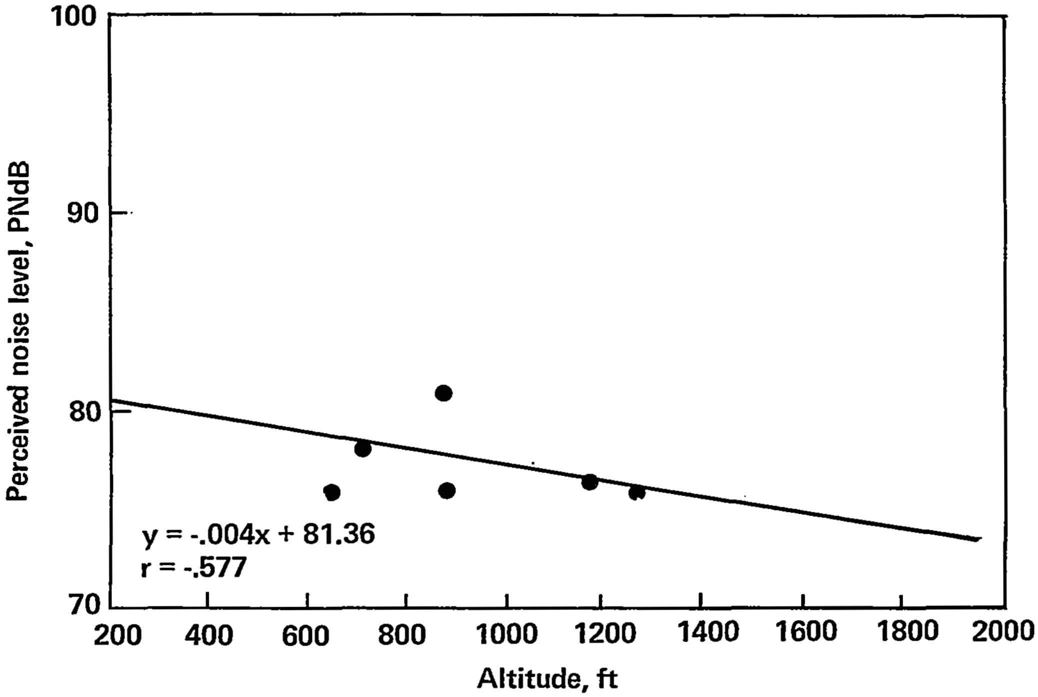


FIGURE 29.—RELATIONSHIP BETWEEN PNL AND TREATED AIRPLANE ALTITUDE—POSITION B (SESSION I)

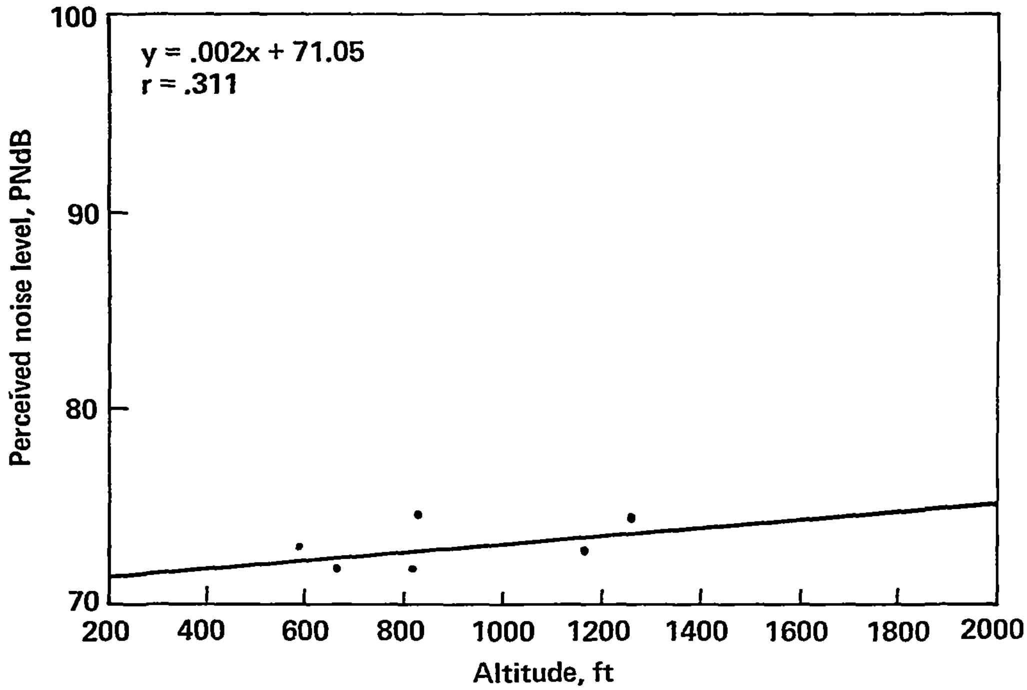


FIGURE 30.— RELATIONSHIP BETWEEN PNL AND TREATED AIRPLANE ALTITUDE—POSITION C (SESSION I)

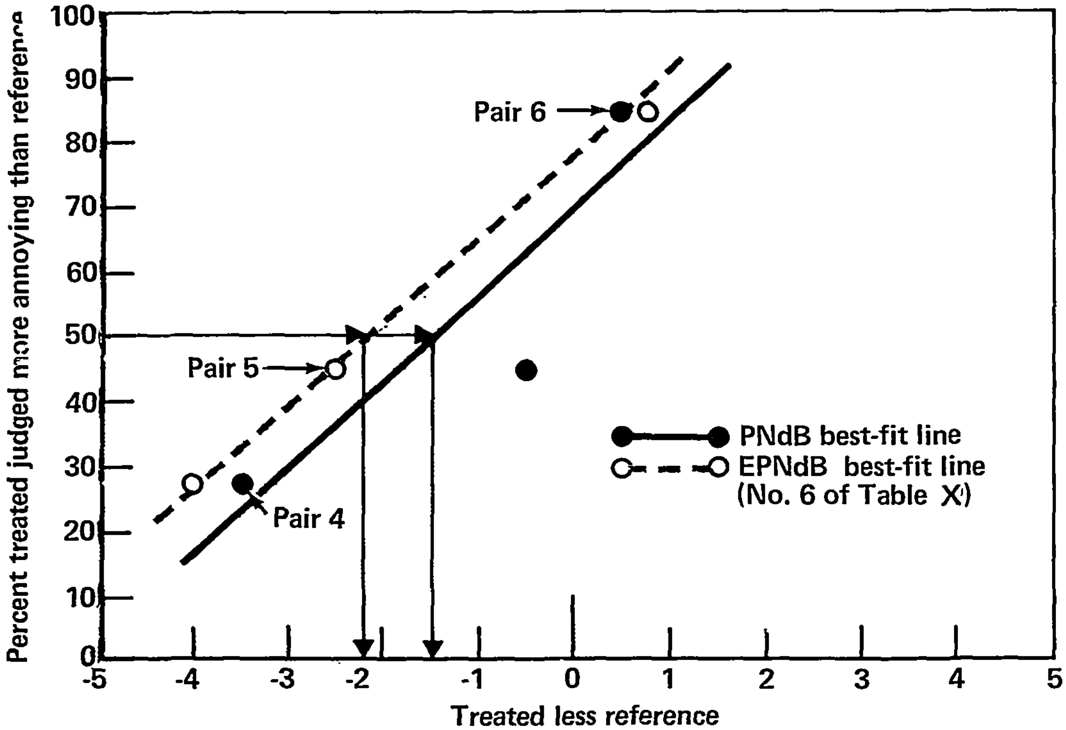


FIGURE 31.—EXAMPLE OF EQUALLY ANNOYING POINT SOLUTION — POSITION D, PAIRS 4, 5, AND 6 (SESSION I)

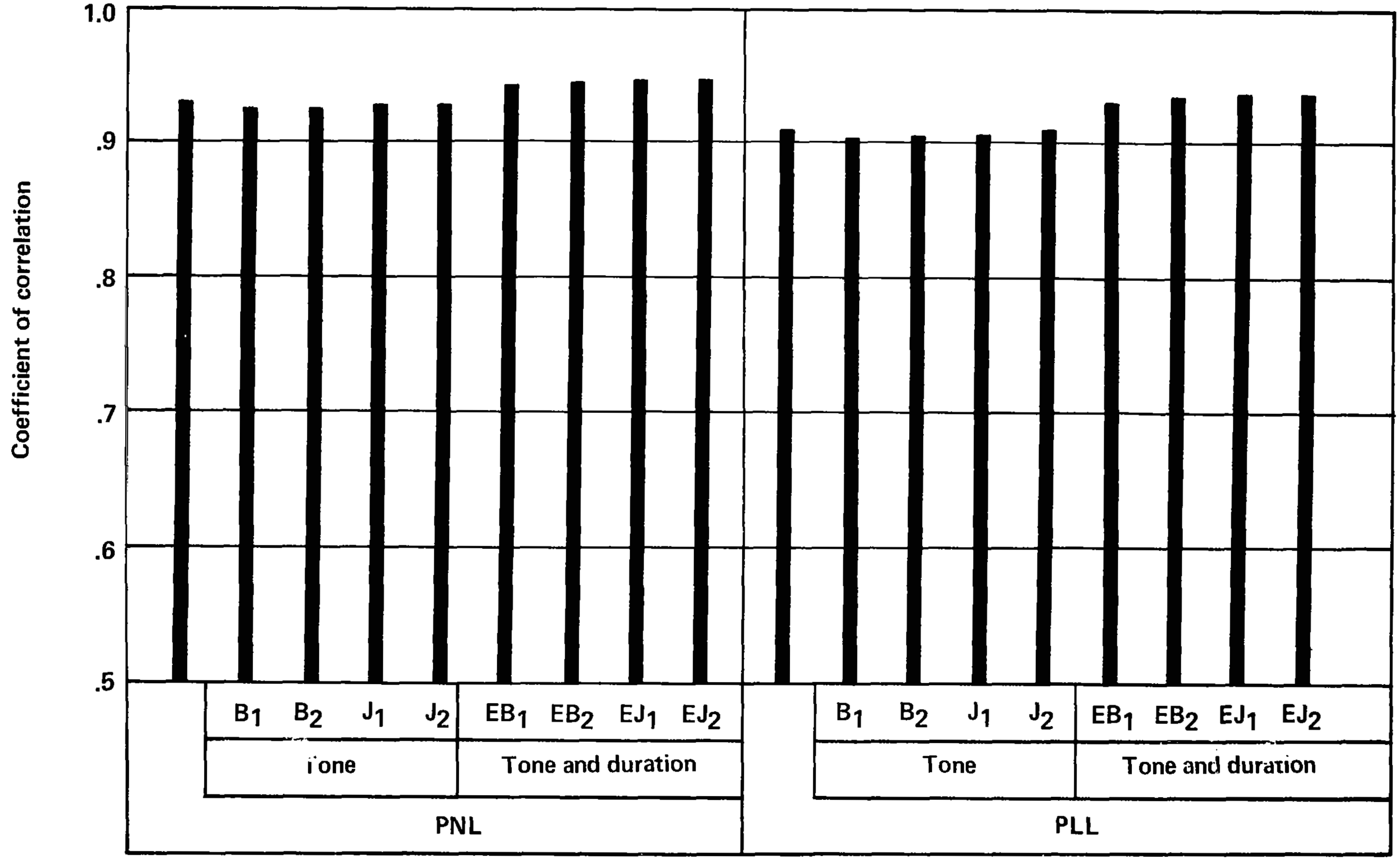


FIGURE 32.—RELATIONSHIP BETWEEN SUBJECTIVE EVALUATIONS AND ENGINEERING CALCULATION PROCEDURES—727 FLYOVERS (SESSION II)

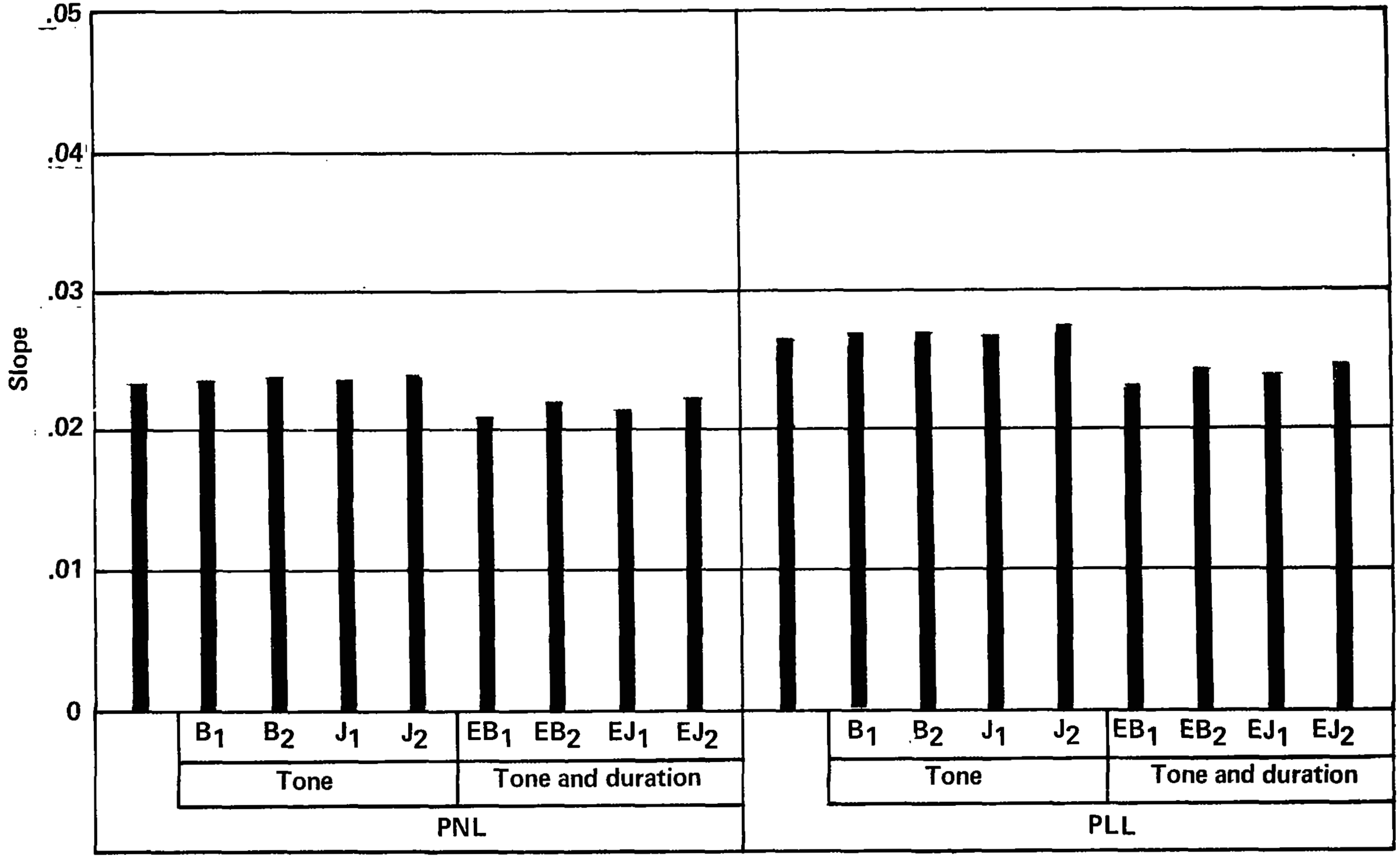


FIGURE 33.—RATES OF CHANGE OF ANNOYANCE—
727 FLYOVERS (SESSION II)

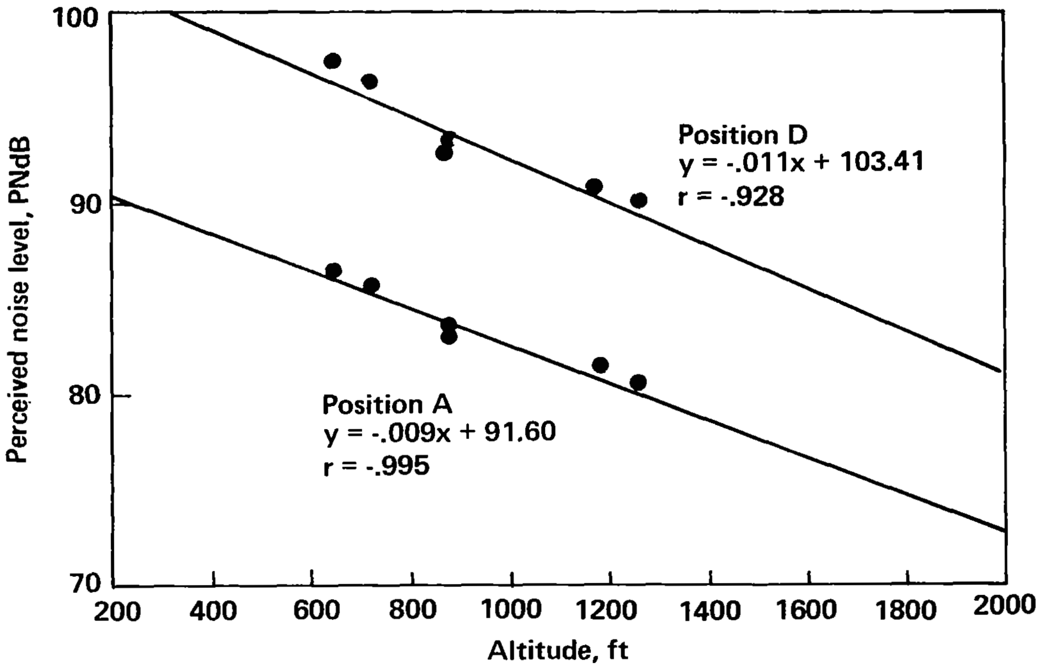


FIGURE 34.—RELATIONSHIP BETWEEN PNL AND TREATED AIRPLANE ALTITUDE (SESSION I)

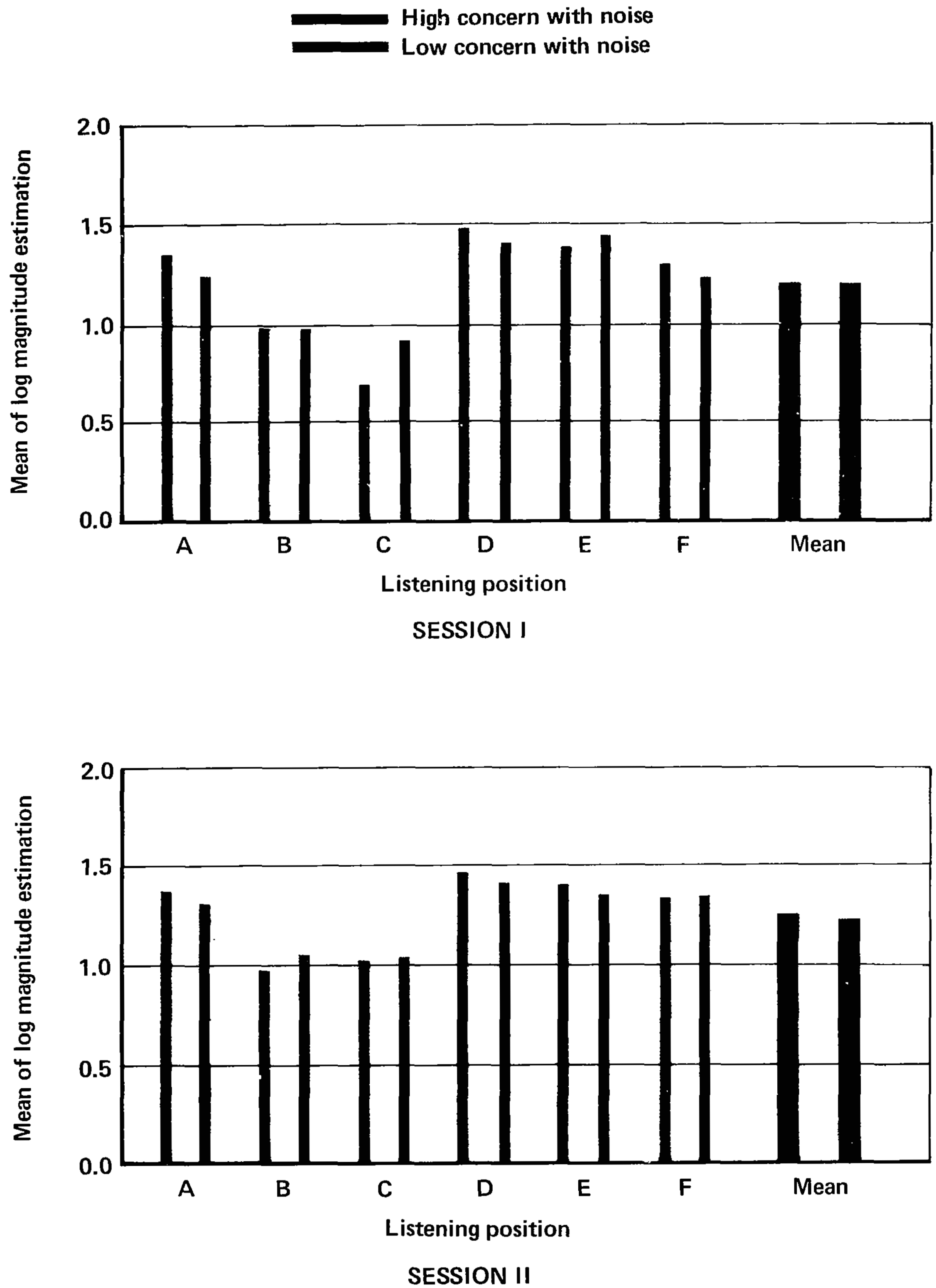


FIGURE 35.– DIFFERENCES BETWEEN MEANS OF LOG MAGNITUDE ESTIMATION RATINGS FOR SUBJECTS REPORTING HIGH OR LOW CONCERN WITH NOISE IN GENERAL

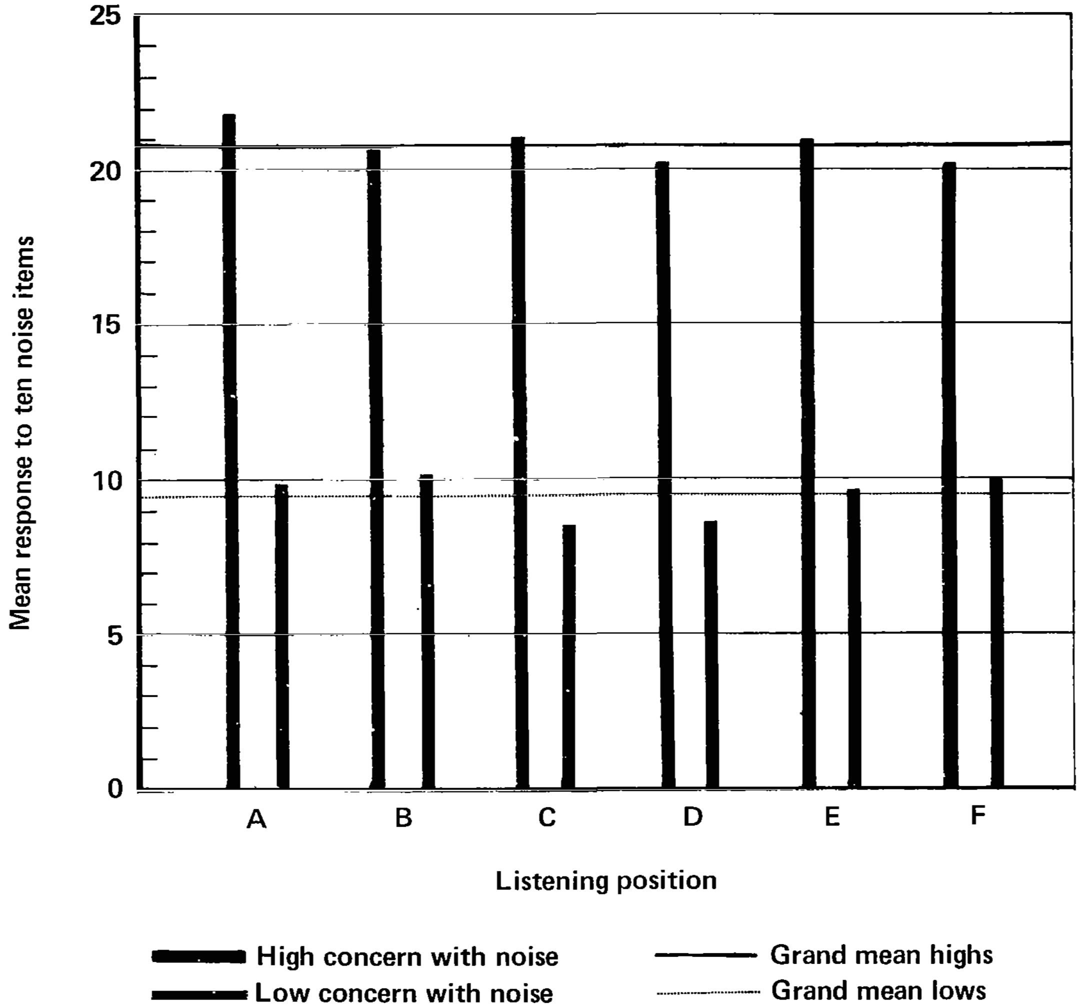


FIGURE 36.—MEAN ATTITUDE SCORES FOR SUBJECTS REPORTING HIGH OR LOW CONCERN WITH NOISE SITUATIONS

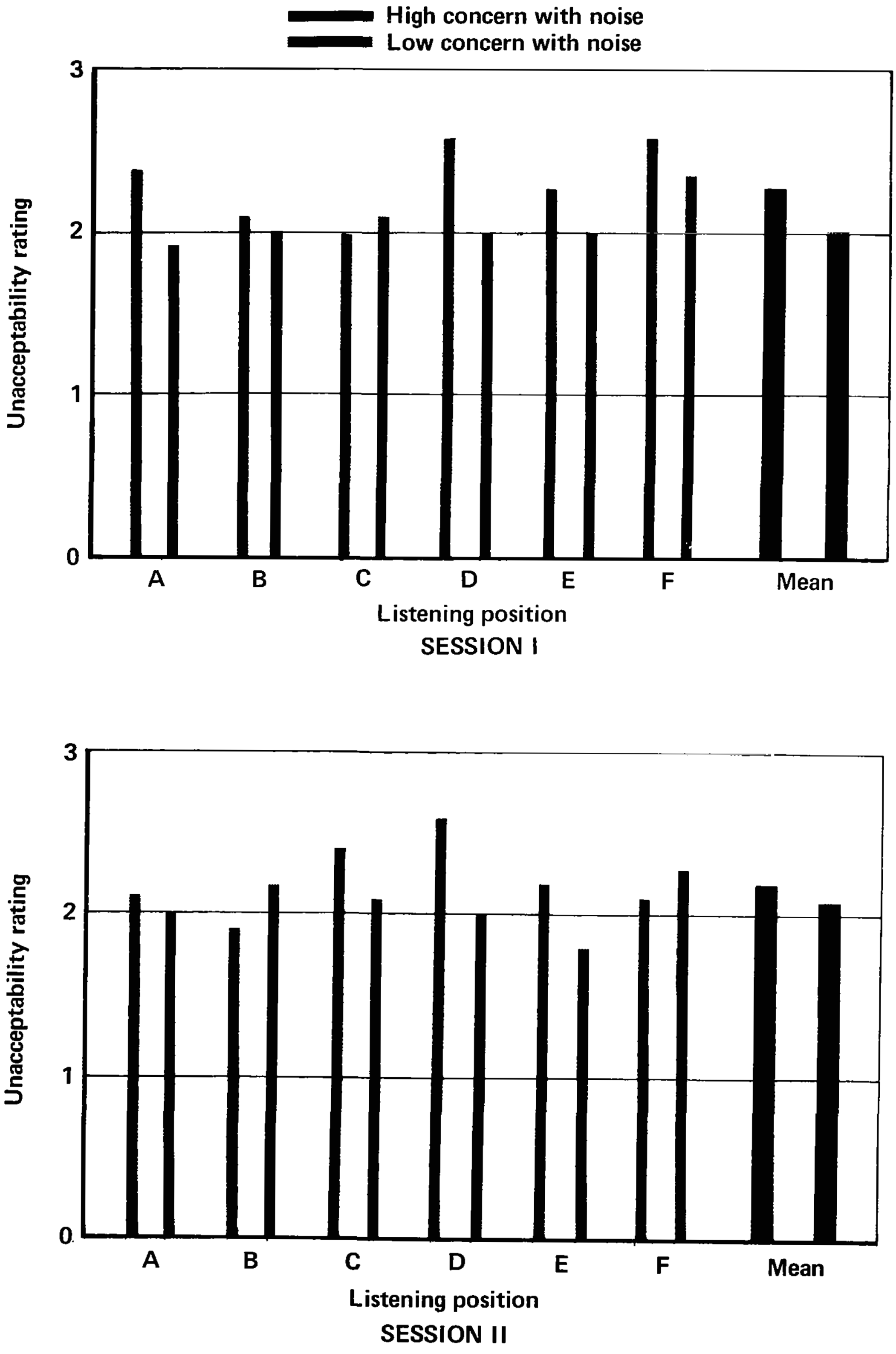


FIGURE 37.—MEAN CATEGORY JUDGMENTS AND CONCERN WITH NOISE

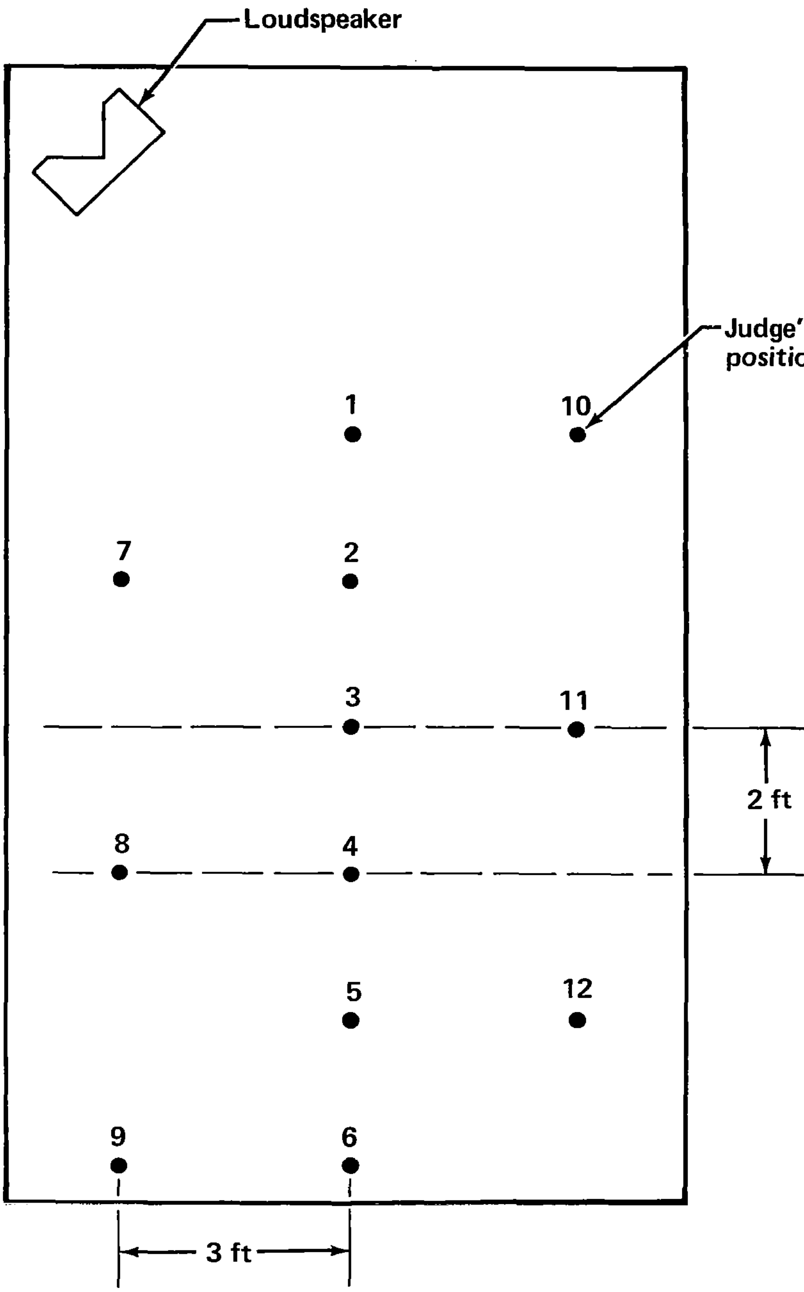


FIGURE A-1.—MEASUREMENT MATRIX FOR INDOOR LISTENING POSITION

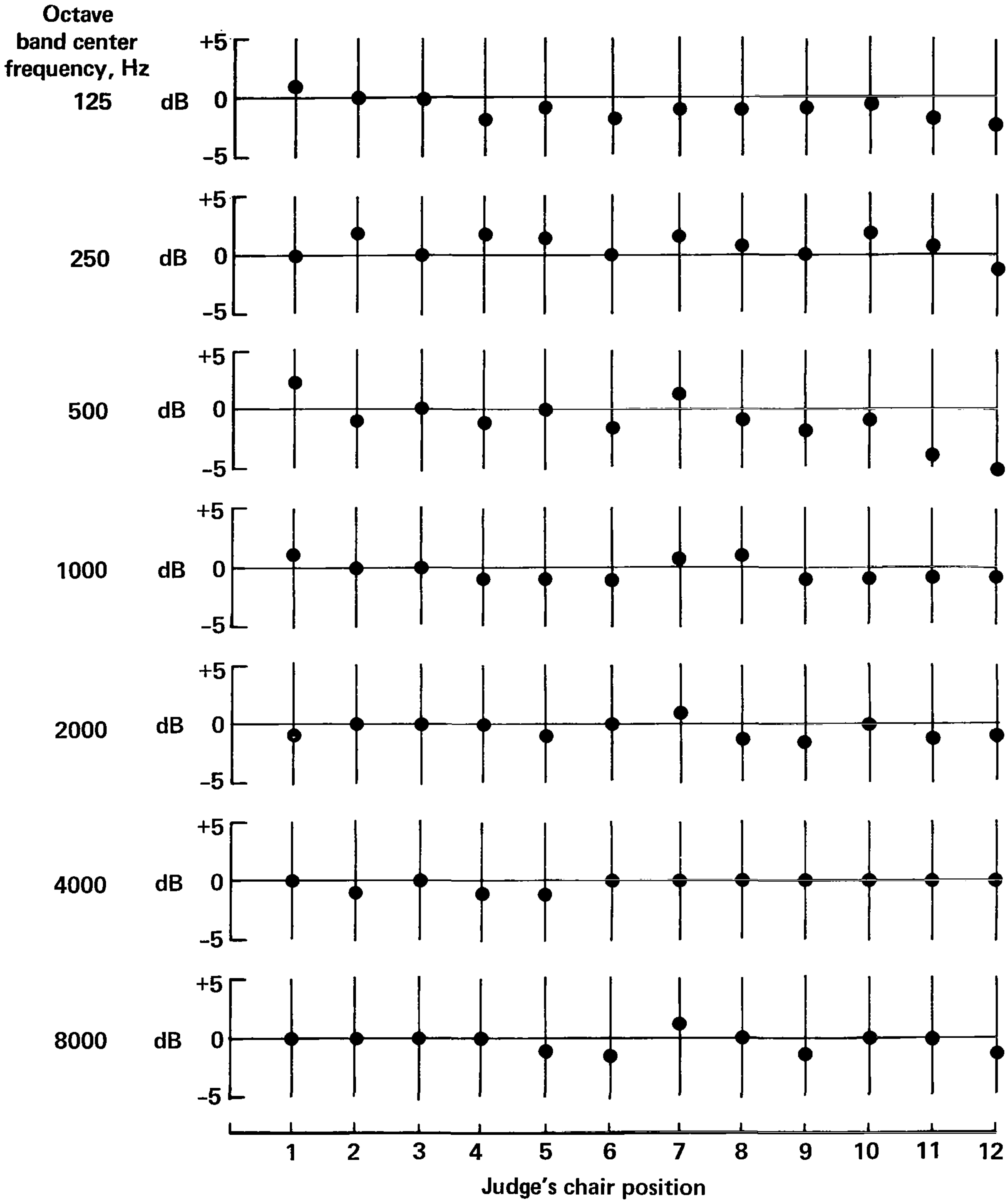


FIGURE A-2.—RELATIVE OCTAVE BAND SOUND DISTRIBUTION FOR TYPICAL INDOOR LOCATION

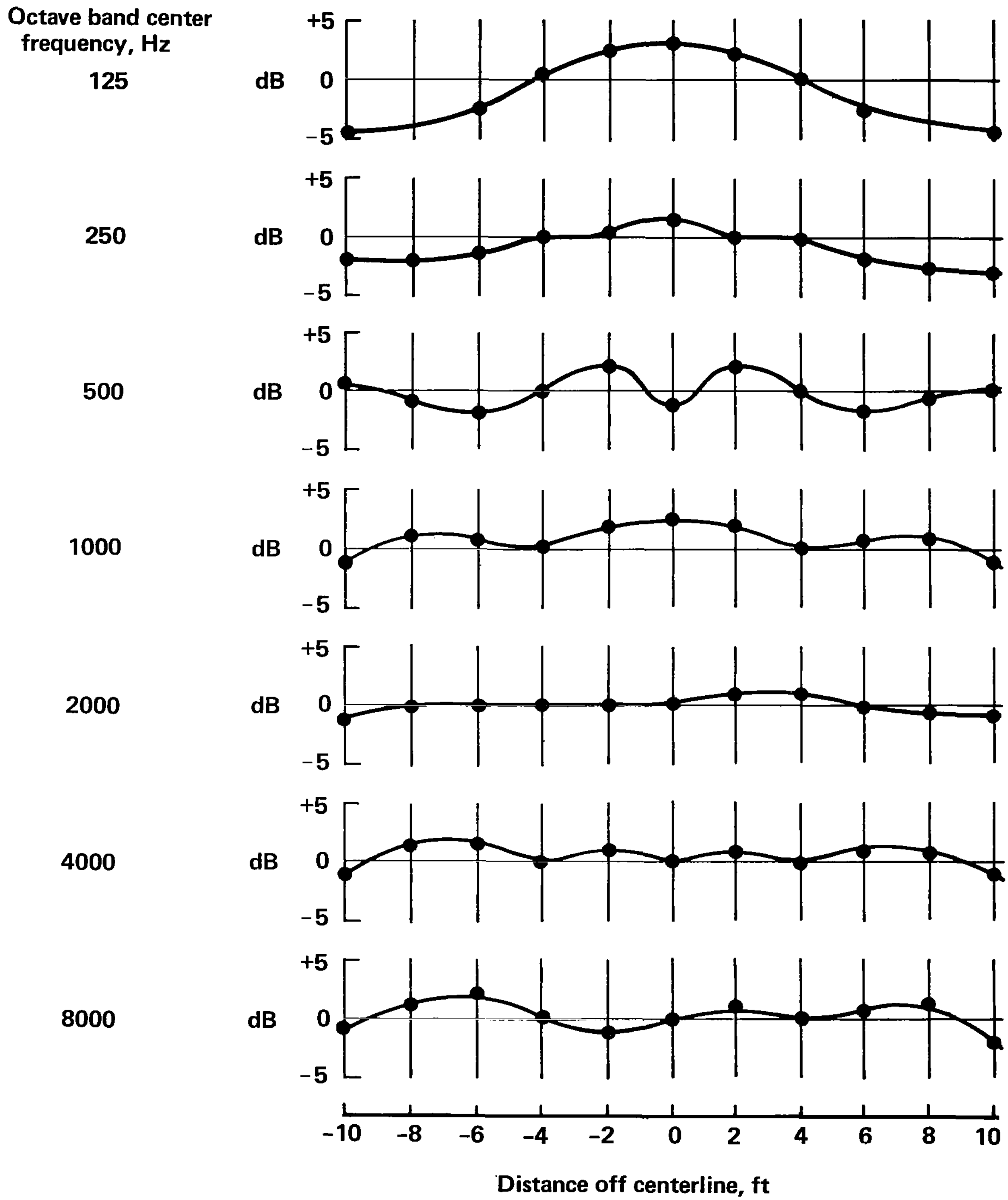


FIGURE A-3.—TYPICAL DISTRIBUTION OF SOUND FOR AN OUTSIDE LISTENING COMPLEX (15 FT FROM LOUDSPEAKER ARRAY)

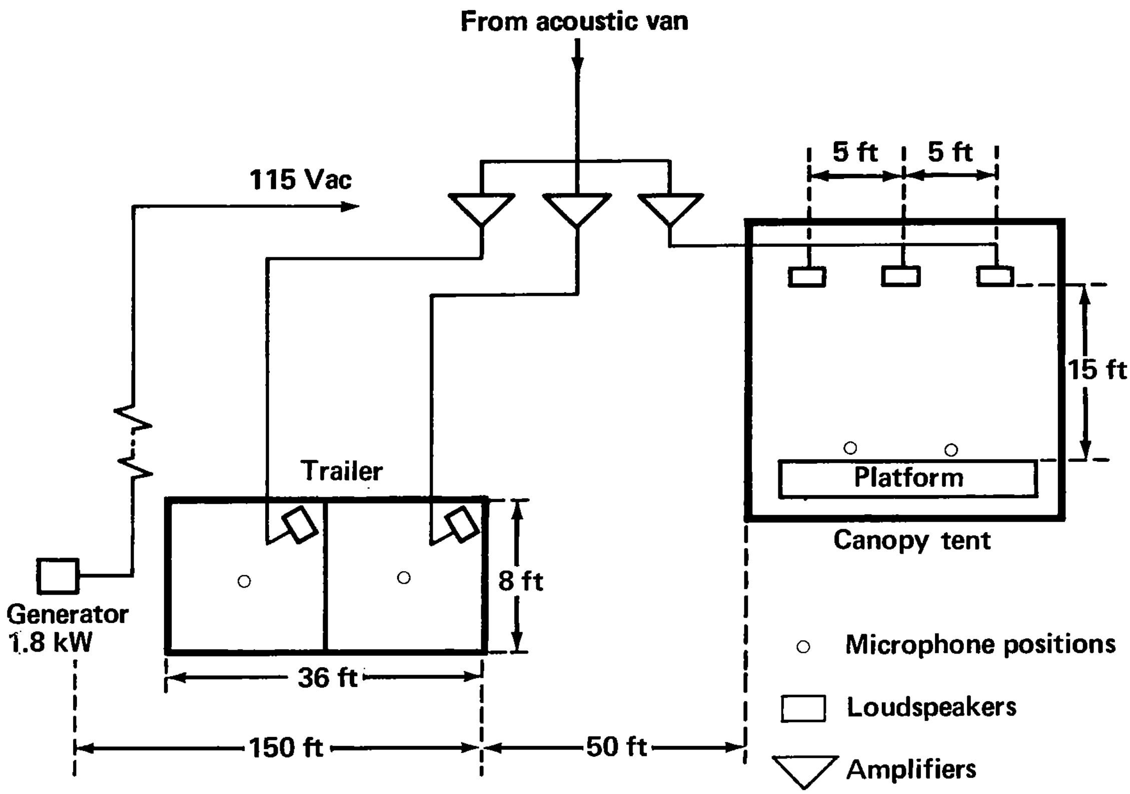


FIGURE A-4.– GEOMETRY OF TYPICAL COMPLEX

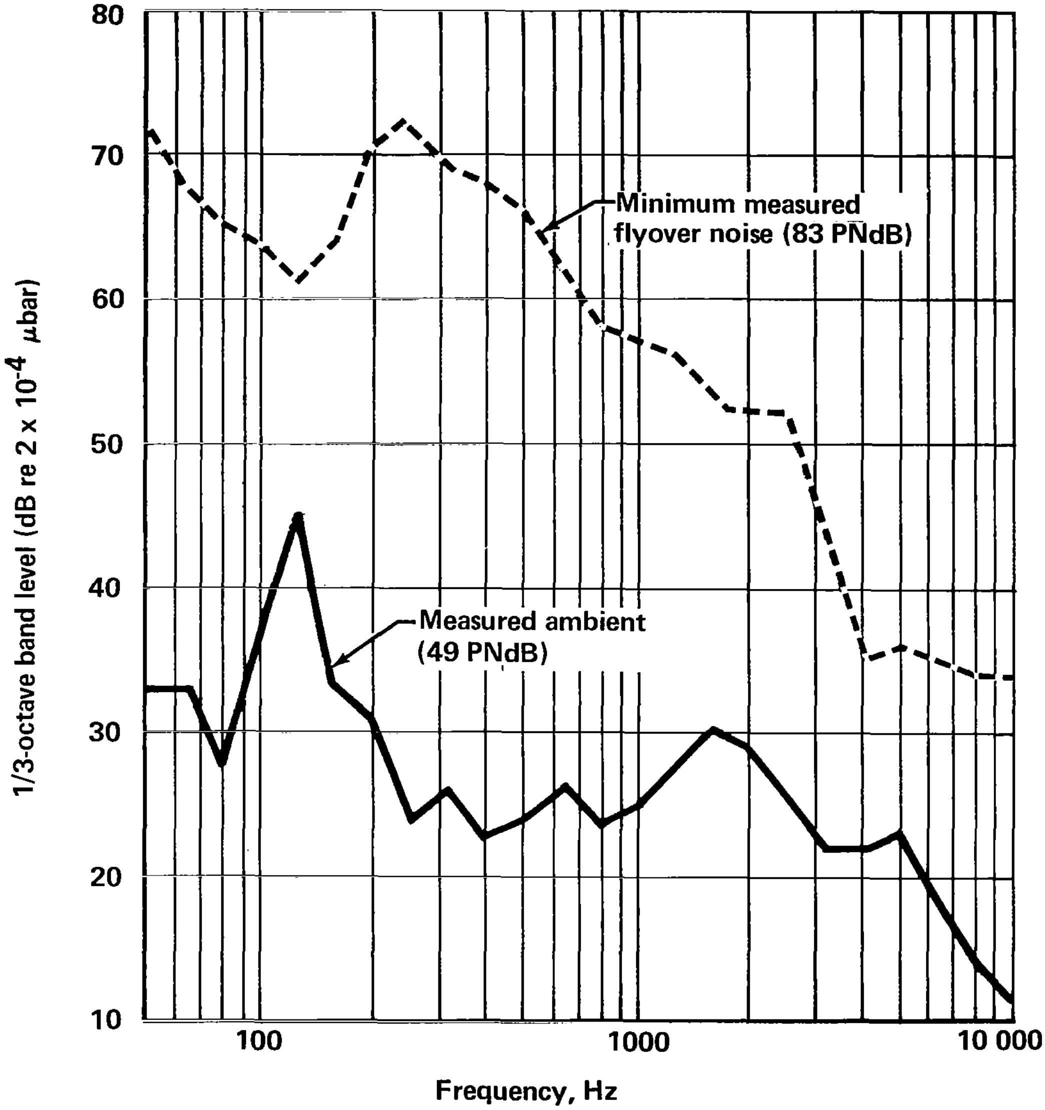


FIGURE A-5.— TYPICAL OUTDOOR AMBIENT CONDITIONS

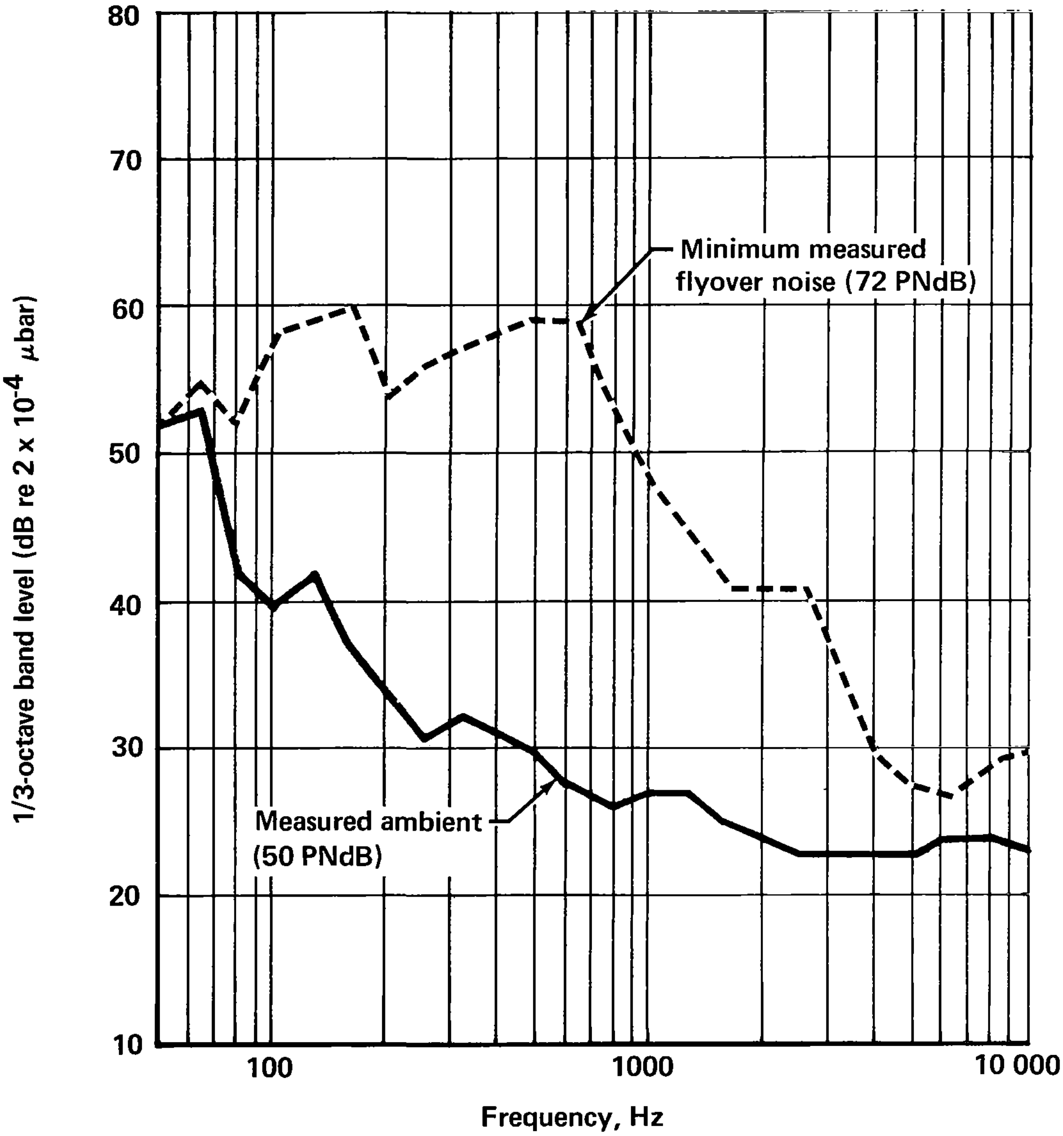
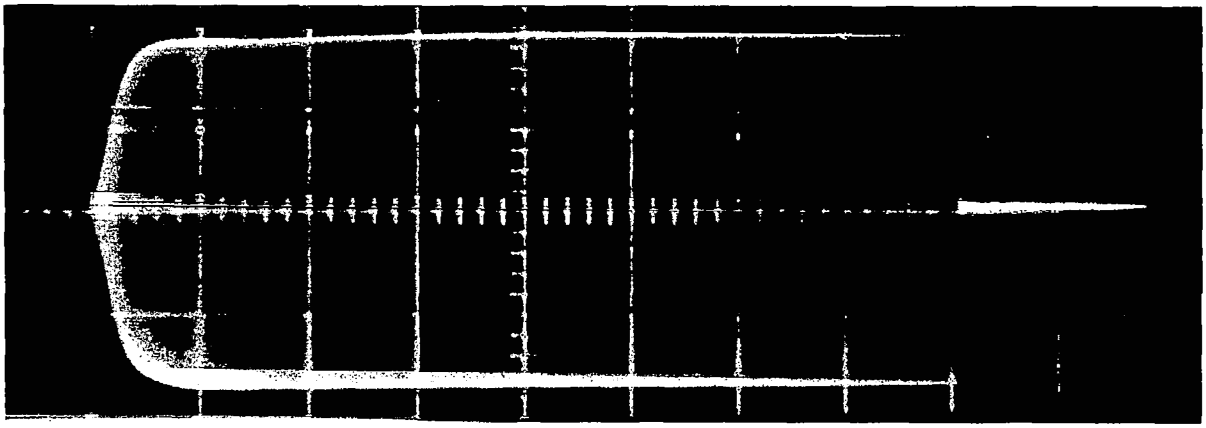


FIGURE A-6.— TYPICAL INDOOR AMBIENT CONDITIONS



0 1 2 3

Seconds

FIGURE A-7.—PULSE ILLUSTRATING RISE AND DECAY TIME OF ARTIFICIAL NOISE

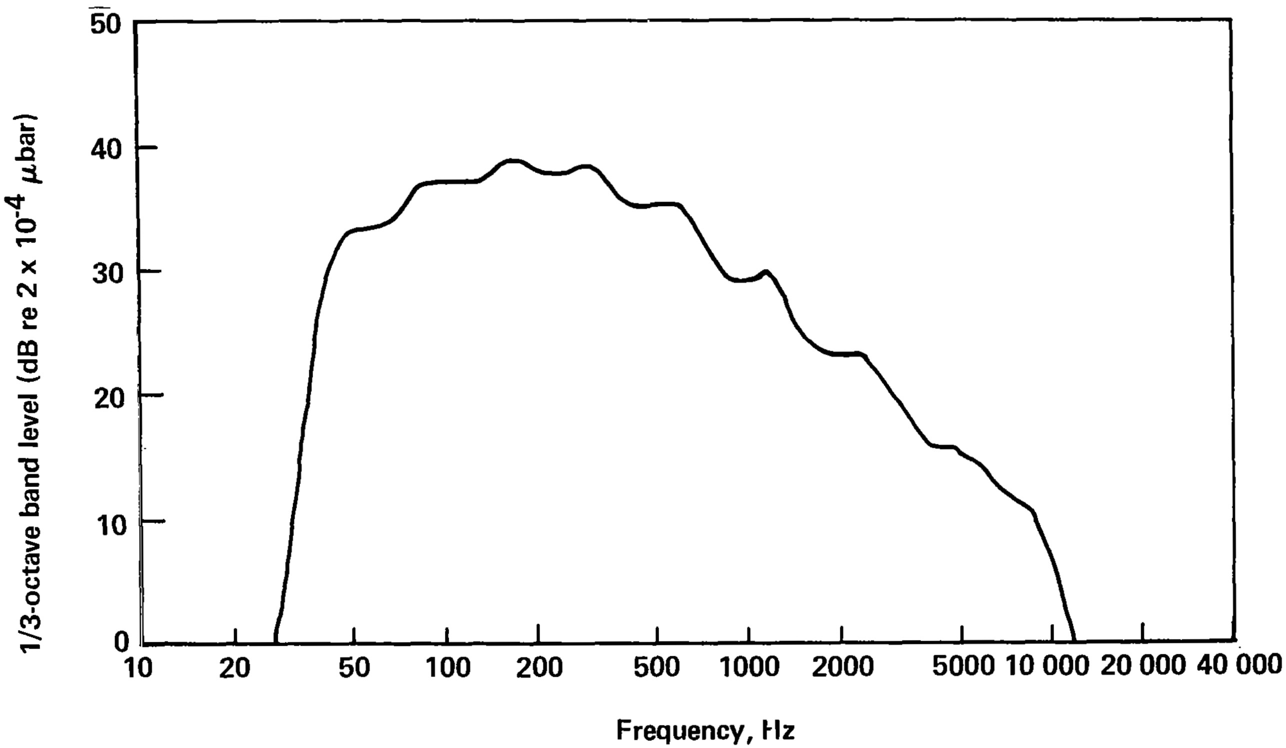


FIGURE A-8.—USASI NOISE—APPROXIMATION OF ELECTRICAL POWER FED INTO SPEAKER SYSTEMS

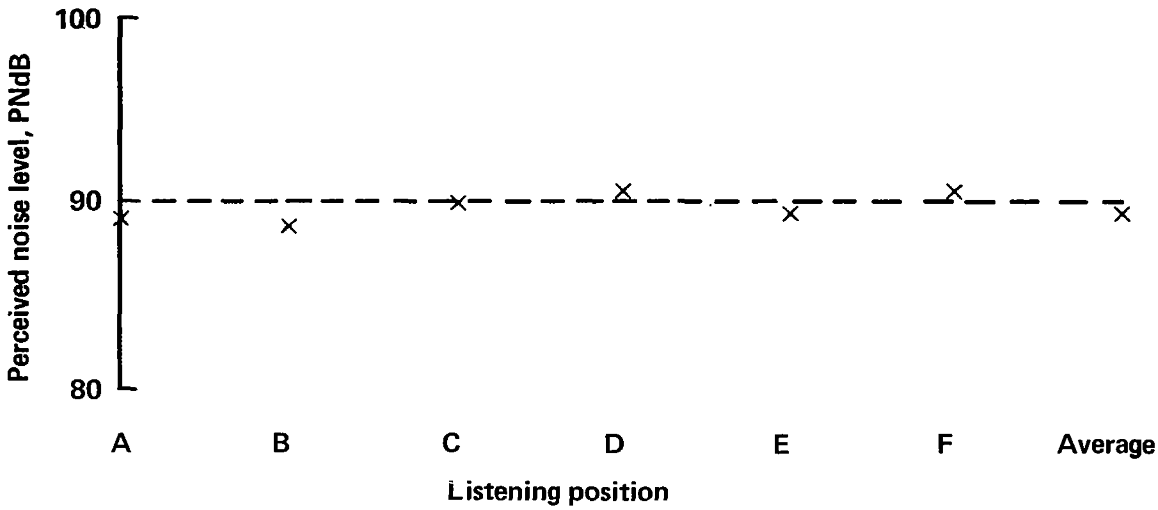


FIGURE A-9.– PRESENTATION OF THE NOMINAL 90-PNdB STANDARD SOUND

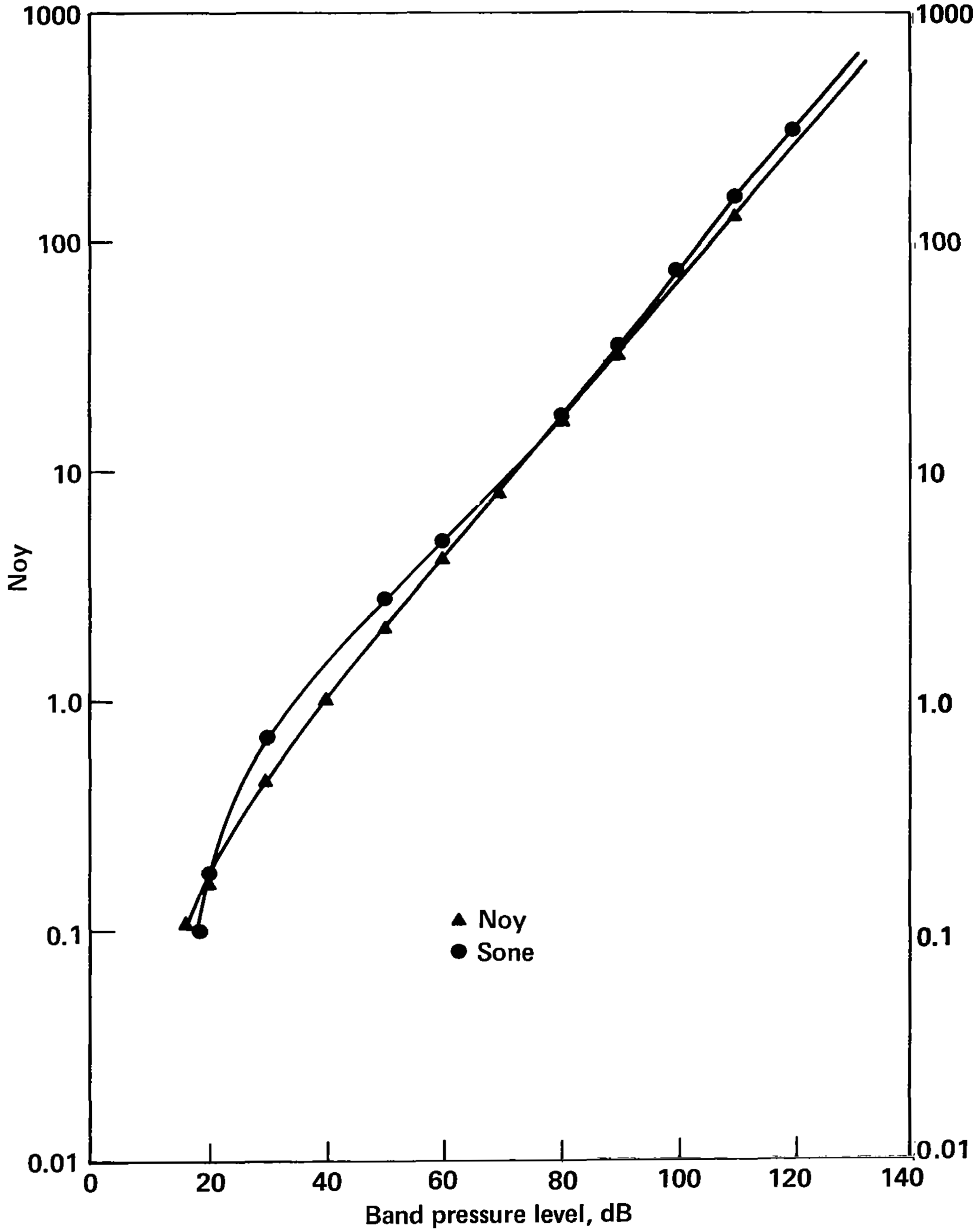


FIGURE C-1.— GROWTH OF LOUDNESS AND ANNOYANCE WITH LEVEL AT 1 kHz

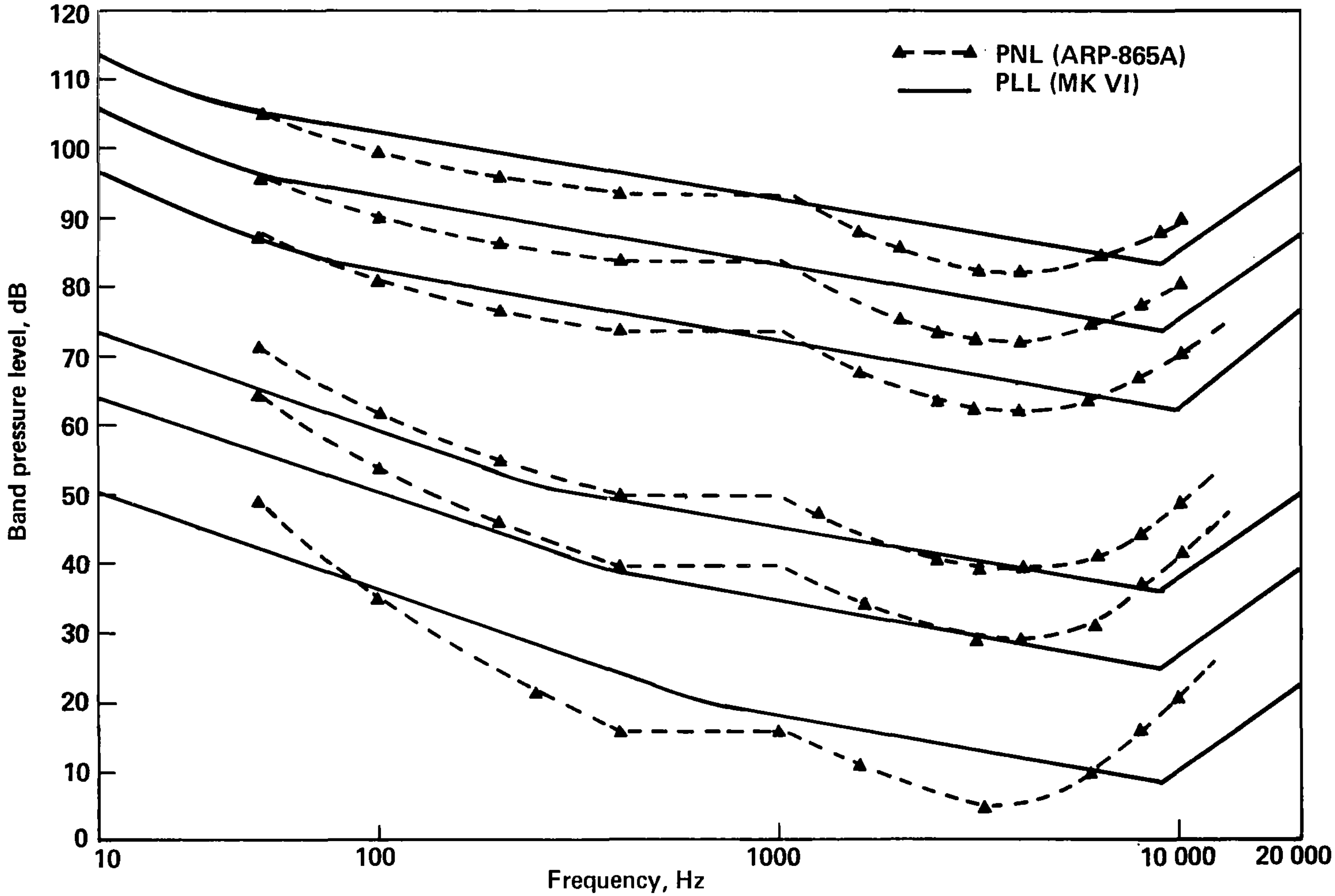


FIGURE C-2.—COMPARISON OF EQUAL ANNOYANCE (PNL) AND EQUAL LOUDNESS (PLL) CONTOURS

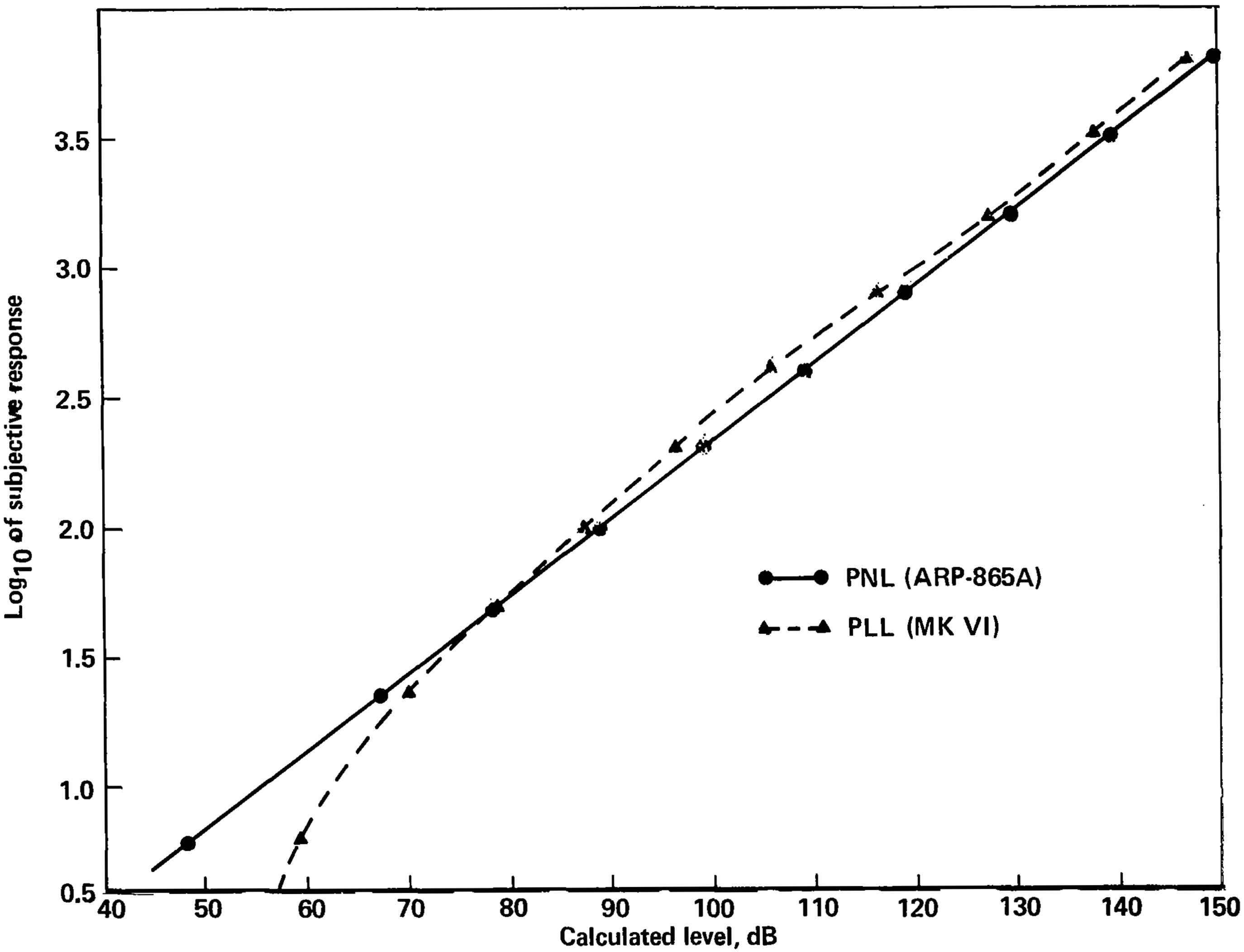


FIGURE C-3.—THEORETICAL FUNCTIONS OF SUBJECTIVE RESPONSE VERSUS CALCULATION PROCEDURE

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